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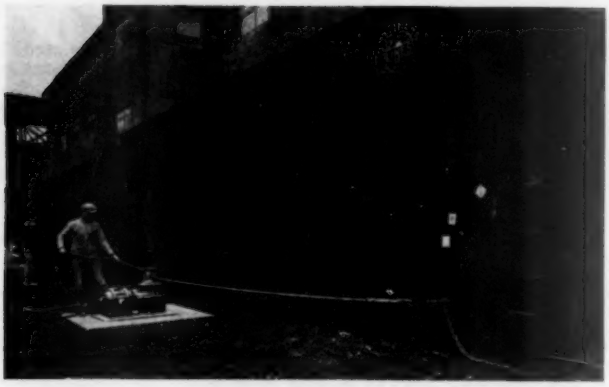

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RECENT DEVELOPMENTS IN THE RECORDING AND REPRODUCTION OF SOUND.*

BY

S. T. WILLIAMS.

Chief Engineer, Victor Talking Machine Company.

As I stand here to-night I picture myself surrounded by those whose efforts are applied to the recording and reproduction of sound. I know that what I say is of them and for them, and my part in it all is small.

On the one hand I see those engaged in research and development work. Beside them I see the design and production engineers. Joined with them I see the thousands in the shops and factories at work. On the other hand, I see the artists and musicians, the entertainers and composers, with the recording laboratory workers.

All are working to bring the world's best music to our homes, at our will, and for our education and enjoyment.

In this group I wish to mention the Bell Telephone Laboratories. Here the basic research and development work in connection with new recording, and the mechanical reproduction was carried out. This development is the application of electrical transmission theory to mechanical transmission systems. A description of this application was presented to the A.I.E.E. in New York last February, by Maxfield and Harrison of the Bell Telephone Laboratories' technical staff.

* Presented at a meeting held Thursday, April 29, 1926.

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I also desire to mention the Radio Corporation of America, and its associates, the General Electric Company and the Westinghouse Electric and Manufacturing Company. In this group the research and development work, as well as the manufacture of electrical parts of the electrical reproducer, have been completed.

To these I desire to add the work of our own Research and Engineering Departments, in balancing and checking up the whole to meet our overall requirements. I am referring particularly to our Physical Research Department under the direction of Doctor Haigis, who has prepared the response charts that follow.

In the discussion and demonstration of the recent developments in the recording and reproduction of sound, I am taking at will from any or all of these, to illustrate the point in question. In a similar manner a unit instrument is made up for production. In leading up to the recent developments, a brief retracing of the history of the art will refresh our memories.

Intelligible sound was first mechanically produced at the beginning of modern science in the seventeenth and eighteenth centuries.

The first knowledge of the nature of sound was then brought to light. As a result a number of machines were made which could produce speech sounds, words, and in some cases entire sentences. These machines might more properly be called producers rather than reproducers of sound.

During the last half of the nineteenth century, our present-day reproducer began to take form.

In 1856 Scott invented the first direct ancestor of the phonograph.

The phonautograph, as his device was called, recorded sound waves but did not reproduce them. In this machine external sound waves were impressed upon a diaphragm which actuated a stiff hogs' bristle bearing on a cylinder coated with lamp-black. By revolving the cylinder and moving it along under the bristle, during the recording, a helix of the impressed sound wave was traced in the lamp-black.

In addition to this device a patent was issued to a man named Fenby for the electrical recording and reproduction of sounds, but nothing more was ever heard of it.[1]

[1] "Reproduction of Sound," Seymour.

The culmination of the various efforts came when Edison invented the first actual phonograph in 1878. Similar in design to Scott's phonautograph, this machine recorded the sound waves on a tin-foil-covered cylinder. By causing the needle to retrace the path that it had made in the tin-foil, the sound waves were picked up and transmitted to a diaphragm which communicated them to the air. The quality was very poor, so poor, that the phonograph was regarded for a time as little more than a scientific novelty.

As a commercial article the phonograph began to gain prominence with the invention of the wax record and the gouge-shaped sapphire cutter. These improvements by Bell and Tainter so bettered the quality of the reproduced sound that much public interest was attached and many minds were turned toward perfecting sound reproduction. For a short time following the invention of the wax blank every record had to be an original or master record. However, the duplicating machine which traced a number of records from the original was soon developed, and this in turn was replaced by the present electroplating process by which a metal die of the original record was made and used to press out a number of copies in a plastic material.

Many different types of reproducers, records, and recording processes were developed by experiment during the early days of the phonograph. Berliner and Johnson were responsible for the disc form of record with lateral cut groove almost universally used to-day.

During the pioneer days of thirty to thirty-five years ago, the talking machine although a commercial article was still a crude device, as can be seen by examining the two machines of Figs. 1 and 2. In the first, the motive power is supplied through a hand crank and the speed is controlled by a governor much like those used on modern motors. (Fig. 1.) In the second the driving power is furnished by a spring motor. (Fig. 2.) The quality is somewhat better than in the hand-driven machine, and certainly the turntable speed is more uniform. The second machine shows the first step toward greater beauty and convenience of operation.

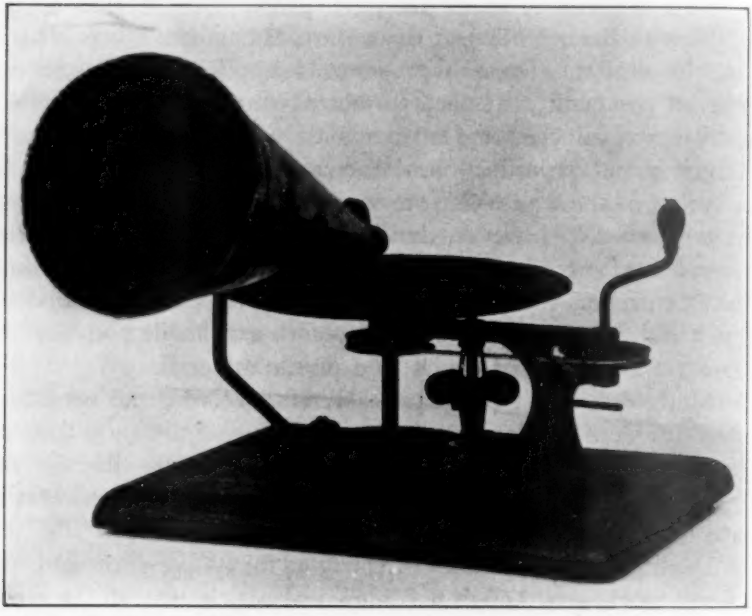
During the next eighteen years many refinements were made in the recording processes and in the materials used in the manu-

facture of records. The size of the records gradually increased until the present ten- and twelve-inch records became almost universal. The world's best music came to be recorded and large industries were built up around the talking machine.

The instrument likewise was refined. The most marked change was that of incorporating the horn in the cabinet, and the gradual evolution of the talking machine in its present form.

In spite of the great amount of time and effort expended dur-

FIG. 1.



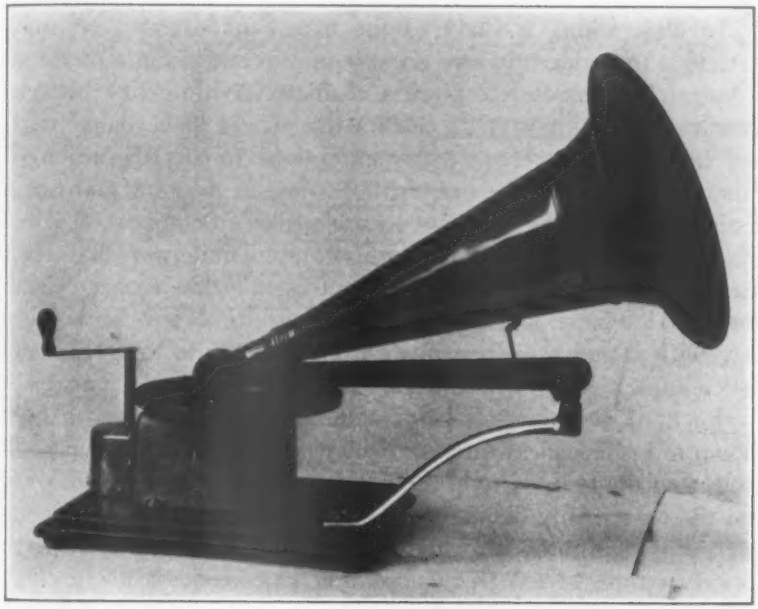
The early talking machines were hand operated, and reproduced with but little quality or character.

ing this period it can in no sense be said that the design of a sound-reproducing mechanism had reached the stage of being an exact science. Many attempts had been made and many theories advanced by able men seeking to formulate the mass of unrelated facts into a reasonable sequence but without exception all such attempts had met with failure. It is doubtful if the action of any other universally used device was so shrouded in mystery as the action of a phonograph. A complete theory connecting the great series of disjointed facts was still lacking. Development along

empirical lines had about reached its utmost and the art of sound reproduction had come practically to a standstill in its progress.

At this stage telephonic knowledge and theory had arrived at such a high degree of development in combating problems similar to those of sound reproduction that it became possible to apply some particular telephonic knowledge to sound reproduction and produce the first consistent theory of the action of a phonograph. The construction following this theory has given

FIG. 2.



Convenience of operation and greater beauty went hand in hand with the development of the reproducing mechanism. Here is a popular model of twenty-five years ago.

such successful results that the art of sound reproduction has received a new impetus.

Before describing the recent developments in the art, all of which have appeared during the past year, a short review of the nature of sound with special attention to the requirements for its accurate reproduction will enable us to understand why and how the new developments were brought about.

Sound may be described as a sensation in the brain resulting from an excitation of the auditory nerves. The source of the

excitation is usually a vibrating mass and the vibrations are ordinarily transmitted through another mass, the atmosphere, to the auditory nerves. The vibrations of the body acting as the source of sound cause condensations and rarefactions in the surrounding atmosphere which spread out in all directions as longitudinal wave motion.

We are concerned ultimately only with such vibrations in the air as are capable of exciting the auditory nerve, and with the problem of measuring these vibrations with a calibrated electrical ear.

In undertaking a study of the nature of sound a common method is to divide it in two classes—noises and definite tones. It is not an easy matter to place a clear-cut dividing line between these two kinds of sound. Such a line would have many twists and turns, for there are many exceptions to any definition of either kind that may be put forth. Without drawing too fine a distinction it will be sufficient to use Miller's definition, "Tones are sounds having such continuity and definiteness that their characteristics may be appreciated by the ear; these characteristics are pitch, loudness, and quality." In our short review we will deal only with sound as it manifests itself in definite tones and not with complex noises whose nature is such that they defy analysis.

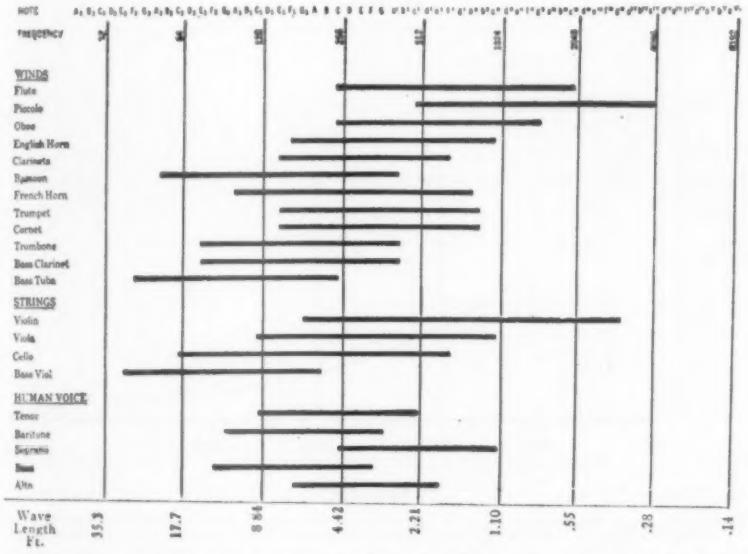
Each of the characteristics enumerated by Miller has been shown to be dependent on a particular property of the wave form producing the tone. Pitch, the first tone characteristic mentioned and the most easily distinguishable to the ear, is dependent upon one thing, the number of complete cycles of the wave in given period of time, styled frequency. Let us consider a phonograph record on which all of the wave forms are identical, differing only in the number of oscillations in a unit of time, the number decreasing as we approach the centre of the record. It is evident that the pitch lowers with a decrease in frequency, and that by a study of its frequency any tone may be placed in its proper position in the musical scale. Many methods of accurately determining the frequency of a tone have been developed but will not be discussed here. A short enumeration of various common frequency values will, however, be given in order to define the frequency range which should be covered in reproduction.

Below and above certain frequencies sound is inaudible,

although the atmospheric disturbance is still in existence, the low limit being about 16 vibrations per second and the upper limit between 20,000 and 25,000 vibrations per second. These limits vary with the individual just as ocular sensitivity to color varies from person to person. An interesting fact which has been established is that the audibility band for any one person usually decreases as the person grows older, a great reduction in ability to hear high notes being particularly noticeable.

To reproduce successfully up to 20,000 or 25,000 cycles, how-

FIG. 3.

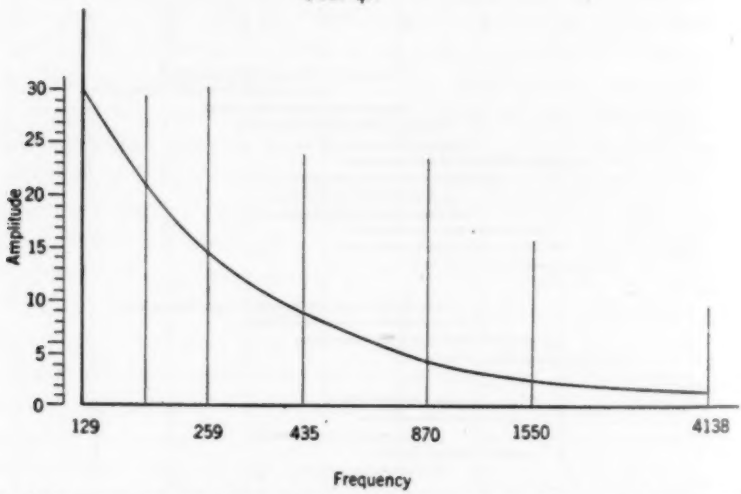


The grand organ alone covers the whole musical scale, with the piano next. We are indebted to *Radio Broadcast* for the above chart showing the range of fundamental tones of the more common producers of musical sounds.

ever, is fortunately not necessary since most of the fundamental frequencies encountered in music and speech do not go above 5000. The common musical scale covers frequencies from 16 to 4138 and only one instrument, the grand organ, utilizes the entire musical scale. For the next instrument having the widest range we must select the piano, which goes to the top of the scale, but stops at 27 cycles per second for its lowest note. None of the other musical instruments can approach these two in range, as is evident from Fig. 3. Among the wind instruments the

piccolo and flute utilize the upper end, the clarinet, cornet and trombone the middle and the bass tuba and bassoon the lower end of the musical scale. Corresponding members of the stringed instrument group may be selected. The human voice is greatly limited also; a good basso may reach as low as 80 cycles and a good soprano can go up to 1100 cycles, certainly not a very wide range when the limits of audibility are considered. All of the frequencies given naturally refer to fundamental tones. From the values enumerated it might appear that a reproducing instrument having a frequency range roughly from 50 to 4200 would

FIG. 4.



As the frequency decreases, the amplitude must increase as shown above, to produce sound of constant loudness. Hence the sound trace on a record increases as the pitch decreases.

be sufficient for all tones of speech and music, but a little more study will show that such is not the case.

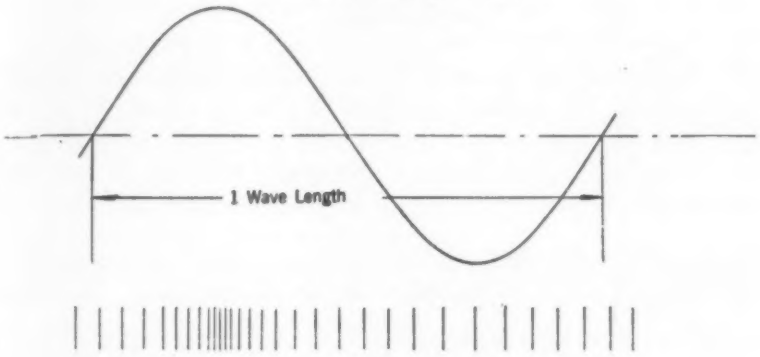
Leaving the discussion of pitch for the time being, the second characteristic of a tone, loudness, may undergo some definition. It is a fact that the loudness of a sound is dependent on a great many factors having to do with the surroundings and the individual ear. For our purposes it will be sufficient to assume that over a wide range of pitch, loudness is dependent on the energy of the wave producing the sound. This energy may be easily expressed in mathematical terms as being proportional to the square of the amplitude and of the frequency of the wave. It is

evident that a slight change in either amplitude or frequency will then produce a great change in loudness. By way of illustrating the square law of intensity Fig. 4, which gives the amplitudes for a sound of constant loudness but of varying pitch, is taken from Miller's "Science of Musical Sounds."

The third characteristic of a musical tone remains to be covered; the peculiar characteristic of quality. It is this characteristic which enables us to differentiate between the note from a cornet and that from a piano though they be of the same pitch and loudness. It even allows us to pick out one violin from among

FIG. 5.

Curve of simple tone given by tuning-fork.

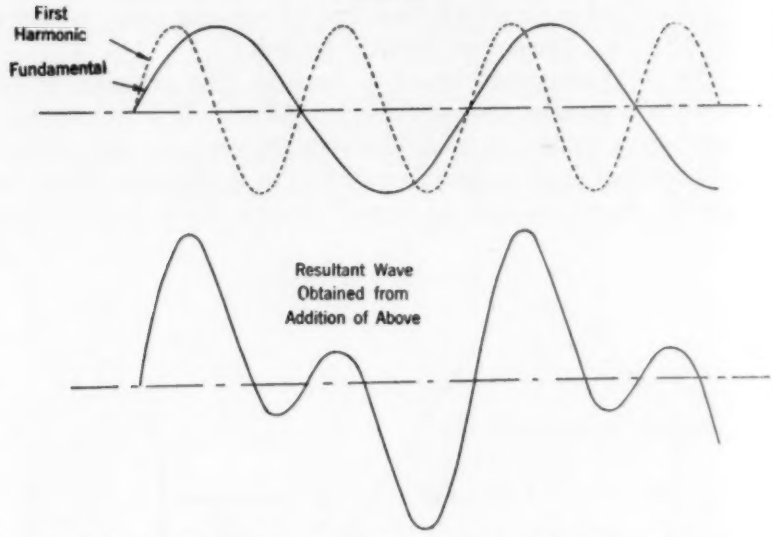


Corresponding wave of condensation and rarefaction in air.

its fellows or any instrument from others of supposedly similar construction. We have already made use of the frequency and amplitude of the wave so that only one property remains, this being the form of the wave. The simplest form of wave is that shown in Fig. 5, the wave of simple harmonic motion such as generated by the vibration of a tuning-fork or of the air in a stopped organ pipe. Such a tone is called a simple or pure tone. Very few musical tones are simple ones, but are of a much more complex nature. However, as is well known, they may all be analyzed as being composites of a number of simple tones, all of which may differ in frequency, amplitude, and phase. The simple tone having the lowest pitch is called the fundamental and all the rest are called partials. If the partials are integral multiples of the fundamental, as is common in music, they are harmonic:

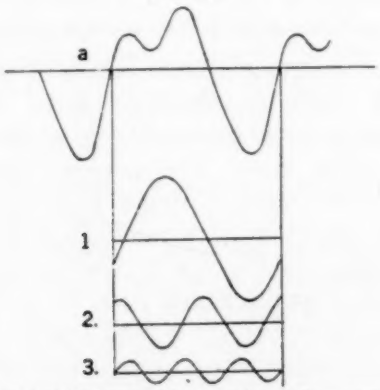
if not, they are inharmonic. Fig. 6 illustrates the combination of a fundamental and its first harmonic partial, the resulting wave

FIG. 6.



being entirely different from either one of its components. The trace of this note on a record would be of this form. In similar

FIG. 7.



Curve of a violin tone and its three harmonic components.

way it is possible to build up any periodic form of wave by combination of a number of simple waves. As an illustration of an actual case, I have here a picture of a violin tone (Fig. 7) which

is composed of three harmonic components. It is in the number, relative magnitude, frequency and phase relation of its partials that the tone of one instrument differs from another, or even from others of the same kind. In short, it is the number and relative magnitude, frequency and phase relation of the partials which determines the quality of a composite tone. The accuracy with which all of these fundamentals and partials are recorded and reproduced determines the character of reproduction on a talking machine.

Having thus briefly discussed the nature of sound, we may continue with the necessities for its accurate reproduction. In the past the development of a reproducing apparatus has been constantly hampered by the lack of an accurate gauge for the measurement of its performance. Our only gauge has been the human ear, which is not capable of scientific calibration. It has been impossible to place two reproducing devices side by side and determine by ear just where one was bad and another good. It has been impossible to discover by ear what was lacking in one machine that was present in another.

One of the outstanding recent developments is that this condition has been eliminated. We have now a method for both the quantitative and qualitative analysis of a given bit of reproduction. This method has been so accurate and definite that it has been our main support and the foundation for trial of all of our development. We are now able to say that one reproduction is better than another as definitely as though we were saying that one automobile can go ten miles an hour faster than a second.

The first step in this direction is to set up a standard of excellence. We will omit any discussion of phase difference or of transient *versus* steady tones and set up our basic standard as follows: All musical notes are made up of an indefinite number of simple tones of various frequencies combined as previously described in fundamentals and partials. It follows that a reproduction which reduces or amplifies the intensities of all the frequencies in the same relative amounts as the original ones is considered perfect. Following out this standard, if we should take a perfect reproducing apparatus and feed into it an always

equal amount of energy in the form of a number of simple tones of different frequencies, the reproducer should in turn radiate an always equal amount of energy at the different frequencies. Depending upon the nature of the reproducer the amount of energy radiated by it may be greater or less than that fed into it from the original source. This makes no difference so long as the radiated energies at the different frequencies are always in the same proportion as in the original sound. If this is not true the reproduction is not perfect and to the degree that the radiated energies depart from proportionality at the various frequencies the reproduction is impaired.

This measurement of reproduction then demands two things: First, an accurate source of energy for the different frequencies, and second, an accurate method of measuring the energy radiated. The first is easy to arrive at for our uses, for it is supplied by constant pure tone records whose amplitude and frequency have been accurately measured.

Having secured a method of applying sound energy to a reproducing system in equal amounts for all frequencies, it is now necessary to devise a method for measuring the energy radiated. These measurements are made in a sound-proof room to cut out all extraneous sounds. The walls of the room are draped to eliminate reflection or reverberation. The actual measurements are made through a condenser transmitter or microphone and vacuum tube amplifying apparatus.

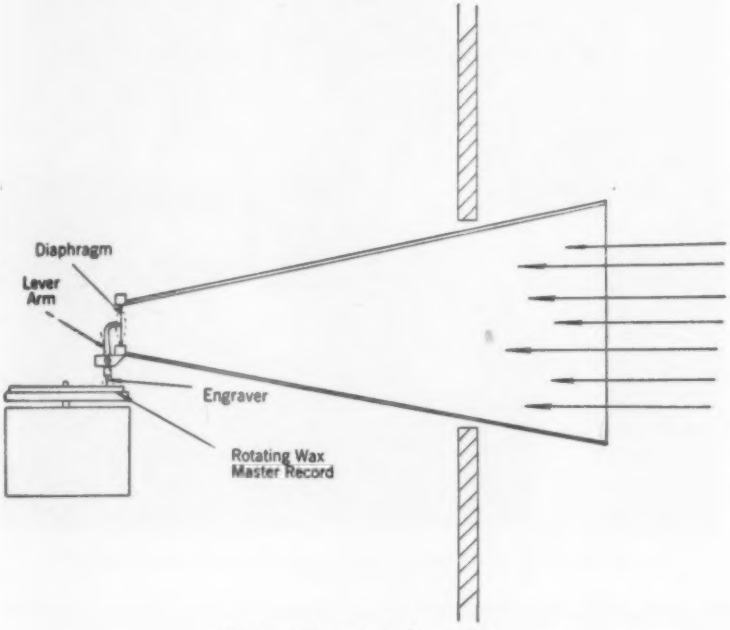
By means of this apparatus we may measure the energy of the sound radiated, and plot a response curve of the reproducing system under test. Not only is the method of charting the radiated sound energy of value in studying complete reproducing systems, but it enables us to isolate any one variable in the system, and determine its effect. This applies to the units of the reproducing system from the tip of the needle to the mouth of the horn. In the lantern slides to be shown later, the effect of certain variables on the response will be clearly shown.

After this preliminary review of the nature of sound and the basis and method of grading sound reproduction, some of the recent developments can be better explained.

A start may be made at the beginning of all sound reproduc-

tion where it becomes necessary to capture the complicated transient waves from the air and imprint them upon a permanent medium. The familiar mechanical method of recording is shown in Fig. 8. As large an amount of the sound energy as possible was collected by a horn and impressed on a diaphragm. The diaphragm in turn actuated a lever carrying a cutting point at one end, which inscribed the waves spirally on a soft wax disc

FIG. 8.



Mechanical method of recording.

rotating under the point. With all the mechanical ingenuity which could be applied to the problem the record thus made was limited by the amount of energy that could be applied to the diaphragm and converted into cutting force.

The energy available for the operation was very small, so small that the weaker instruments, such as the violin, had to be rigged with a special device in order that they might be heard. An orchestra or band had to be completely rearranged in a compact fashion to give the weaker instruments a chance and some of the powerful instruments had to be removed to a distance or

left out altogether. Fig. 9 shows a picture of a group making a recording under these methods. With the arrangement so altered and everything sacrificed for the proper tone mixture, it was hard to secure the same spirit and obtain as good a rendition as though the arrangement was a natural one.

Perhaps the greatest fault of the old method of recording,

FIG. 9.

A recording room in the old days. Note how the artists are crowded around the recording horn.

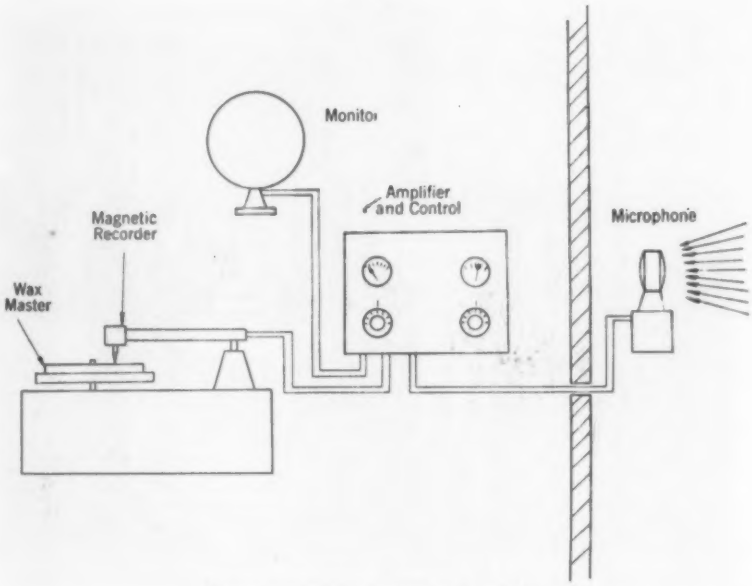
however, was the distortion of the sound waves by the mechanical constants of the diaphragm, lever, and cutter.

The new method of recording eliminates the difficulties of the old to a marked extent.

Fig. 10 shows the new method. The sound waves are collected by a microphone, partly amplified and then conveyed to the main control and amplifying unit. Here they are again amplified and then conveyed to an electrical cutter which cuts a sound trace in the wax disc just as the mechanical cutter did. Connected with the main amplifying unit is a loud-speaking device so that the control operator may listen to the record as it is being made. Since the energy available for cutting the master record is thus

so greatly enlarged, it is no longer necessary to group the musical instruments closely or to change their arrangement to any extent from that used in a concert. The weaker instruments do not have to be strengthened nor the powerful ones reduced for a recording. All in all the musical conditions are similar to those for a regular concert, consequently the selection is more likely to

FIG. 10.



Electro-mechanical method of recording.

be perfectly rendered than by the old method of recording with its altered conditions. By placing the instruments at a greater distance from the microphone the tones are blended by room reflection and are thus given the characteristic "room tone" which would be heard by one listening in the usual manner. Fig. 11 shows a picture of a group of musicians making a new recording and is a great contrast to the other picture.

With all these evident advantages the new system has been designed to give further advantages over the old one which are not so evident. By using a condenser transmitter for a pick-up and transformer of mechanical sound waves into electrical ones a distortionless system of transformation has been developed. In

other words, if the condenser transmitter were subjected to a test of the same nature as previously described in the reproduction test, it would show a uniform energy output for a uniform energy input at all the different frequencies required in its range. A test of the amplifying system would show the same thing as would also a test of the electrical cutter. Consequently the sound

FIG. 11.

Present-day recording through a microphone. The arrangement is the normal one used in recitals.

waves are cut without distortion on the wax disc and appear there in their relative magnitudes, within the required limits.

By the use of the new system then, specially constructed musical instruments, crowding of the musicians and distortion of the recorded waves are eliminated. A greater proportion of the musical range is covered as the system is not subject to the limitations of the mechanical system. The results speak for themselves in clarity, naturalness, and fidelity to the original.

The process of duplicating the wax discs being already satisfactory has undergone no major changes, so no time will be devoted to it. It duplicates the new master records as easily

and faithfully as it did the old, producing thousands of copies from the original, these copies being the familiar form of phonograph record.

In the translation of the grooves contained on the record face into sound waves, however, a change has taken place which presents as many advantages over the old method as the new recordings give over the old.

The solution as applied to the telephone line transmission is called electrically "matching impedances." The electrical solution of this problem has been converted to mechanical equivalents, and applied to the mechanical talking-machine transmission system.

Briefly, a perfect matched impedance system provides a one-

FIG. 12.

MECHANICAL	ELECTRICAL
Force..... F (dynes)	Voltage.....E (volts)
Velocity.....v (cm./sec.)	Current.....I (amperes)
Displacement.....s (cm.)	Charge.....q (coulombs)
Impedance....z (dyne sec./cm. or mechanical ohms)	Impedance .....Z (ohms)
Resistance ...r (dyne sec./cm.)	Resistance .....R (ohms)
Reactance....x (dyne sec./cm.)	Reactance.....X (ohms)
Mass.....m (gms.)	Inductance.....L (henries)
Compliance.....c (cm./dyne)	Capacity.....C (farads)
Elasticity ..... $\frac{1}{\text{Compliance}}$	

Mechanical and electrical analogy.

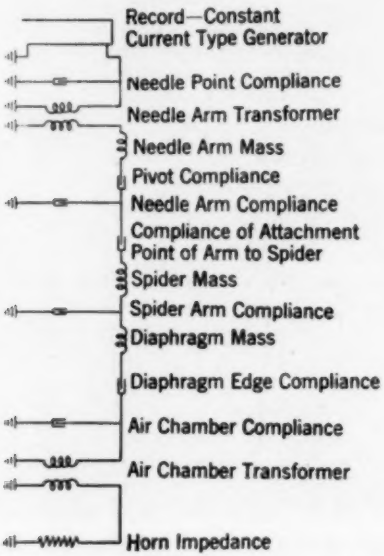
directional flow to energy. Vibrative energy will flow through it without resonance or reflection, and resulting distortion. A mechanical analogy is represented by a series of billiard balls of equal mass and elasticity, placed in contact. Energy imparted to one side of the system is carried through and imparted to the last ball in the system, with but small frictional losses. A difference of elasticity or mass in any of the balls will cause the impedances of the system to be no longer matched, and the even flow of energy is interrupted.

In essentially the same manner, a path for the sound-wave energy has been worked out from the tip of the needle to the horn mouth of the mechanical talking machine. I do not propose to more than outline the fundamentals here, as the formulæ are available to those interested. In brief, the mechanical equivalents of the electrical quantities utilized are shown in the table (Fig.

12). These enter into the calculations in the order shown in Fig. 13.

The physical result of this application is shown in Fig. 14, which gives a cross-sectional view of the new reproducer. As far as mechanical ingenuity can devise this reproducer is constructed in exact analogy to an electrical transmission line designed to give distortionless frequency transmission from 0 to 5000 cycles per second. That we accomplish this range with reasonable accuracy has been proved by actual measurements of mechanical

FIG. 13.



Electric equivalent of phonographic transmission system.

impedance and by making the frequency energy measurements of the regular response tests.

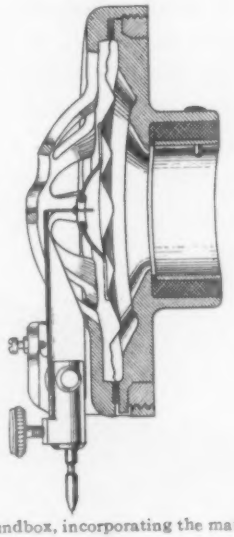
This carries the reproduction of sound to the throat of the horn, mechanically. We will now consider electrical reproduction of sound up to the throat of the horn, prior to our consideration of horn developments.

The electric reproducing system comprises four elements. These are the pick-up; the volume control and scratch reducer; the amplifier, and the loud-speaker mechanism. This system is shown diagrammatically by Fig. 15.

The pick-up is a miniature electric generator, comprising a

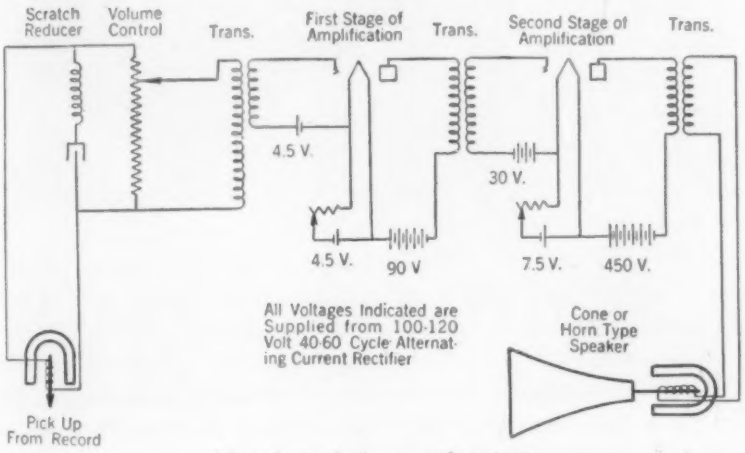
small steel armature carrying the needle in the record groove; and swinging in the field of a permanent magnet. Around this arma-

FIG. 14.



This is a reproducer, or soundbox, incorporating the matched impedance principle.

FIG. 15.



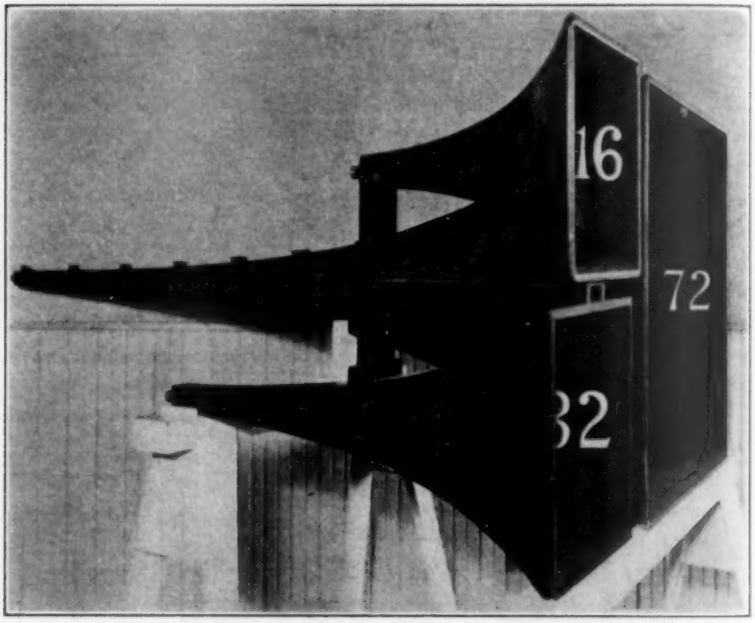
Electrola. 10-inch cone or horn type.

ture is a coil of fine wire forming the armature winding of the generator. The ends of this coil lead through the volume control to the amplifier and loud speaker.

The armature vibrating mechanically under the impulse of the record groove displaces the lines of magnetic force in the field of the permanent magnet. These in turn cut the wires in the field coil, generating a feeble alternating electric current. The wave form of this electric current, if we had a picture of it, would look like the waves that are in the record.

Next in the diagram will be seen the volume control and

FIG. 16.



16-inch, 32-inch and 72-inch straight horns.

scratch reducer. The scratch reducer is incorporated in the volume-control unit and is an electrical filter designed to reduce the audio-frequencies that reproduce as scratch.

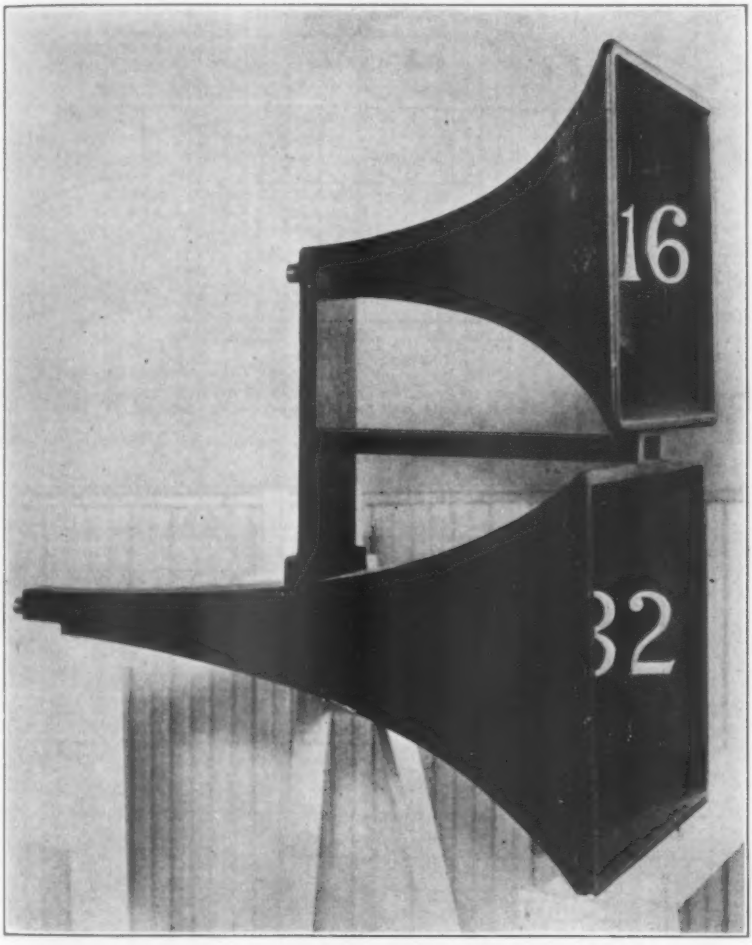
The vacuum tube amplifier used has two stages of amplification and is similar in construction to the audio-frequency amplifier of a radio-receiving set. It amplifies the electrical waves generated in the pick-up. They are then transmitted to the loud speaker, either a horn or cone type, and are radiated as sound.

The impedances of this electrical transmission system are matched to give correct reproduction just as the impedances of

the mechanical transmission system were matched to give correct mechanical reproduction.

Electrical reproduction may then be secured through any of

FIG. 17.

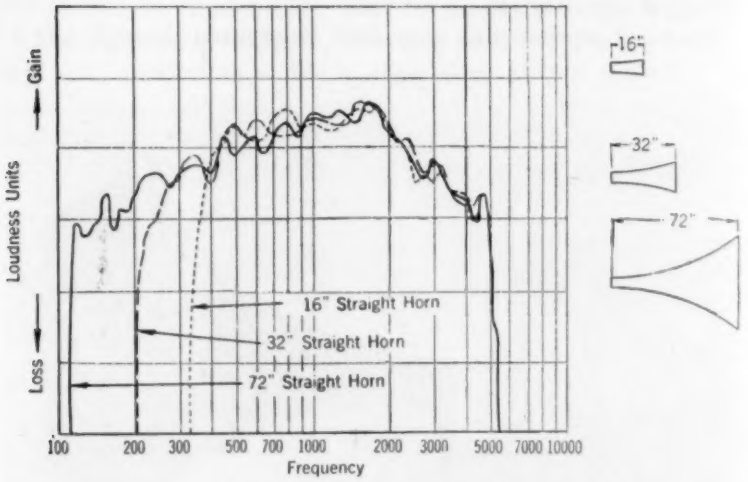


16-inch and 32-inch straight horns.

the commercial radio loud speakers. We are utilizing two types of cone speakers, and a horn type of speaker attachment secured to the talking-machine horn for electrical or radio reproduction.

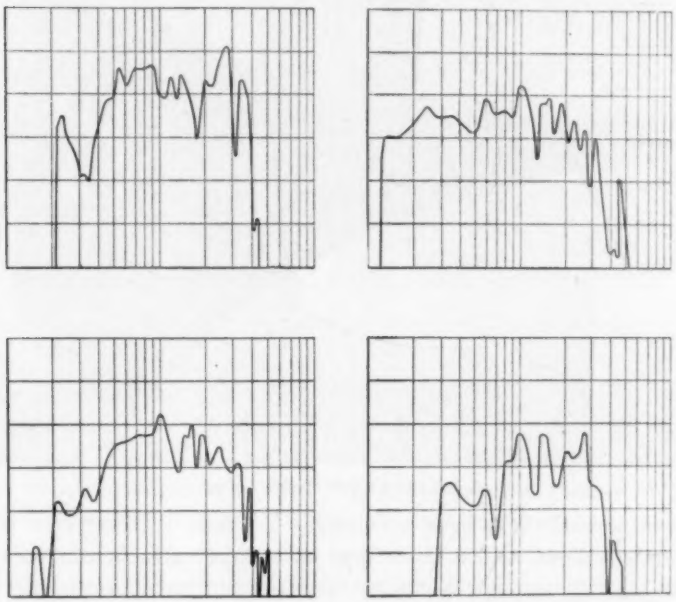
The highest development of the cone-type speaker, operated

FIG. 18.



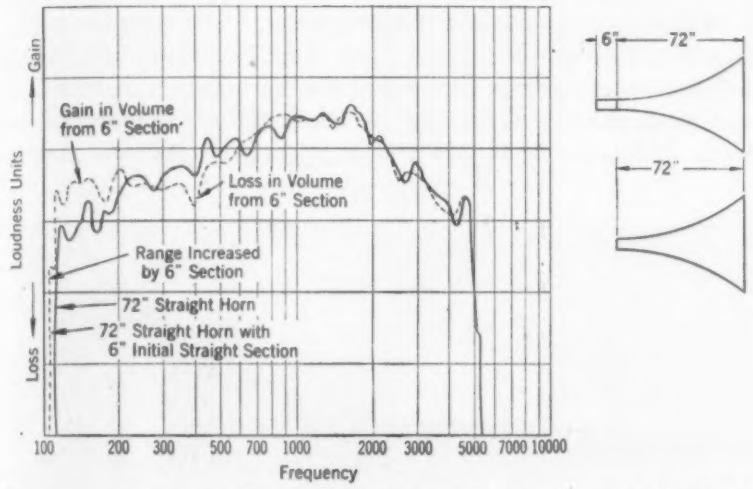
Frequency response curve. Comparison of frequency range of 16-inch, 32-inch and 72-inch straight horns. Response over respective ranges is identical.

FIG. 19.



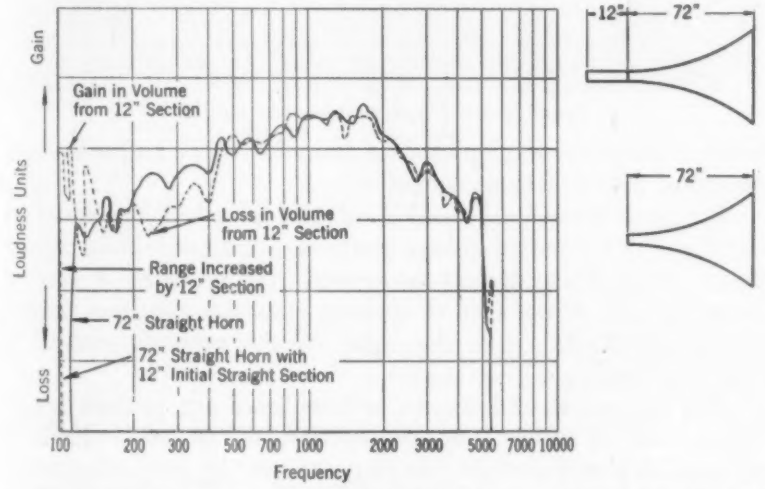
Typical response curves of commercial reproducing systems.

FIG. 20.



Frequency response curve. Comparison of 72-inch straight horn and same horn with initial 6-inch straight section.

FIG. 21.

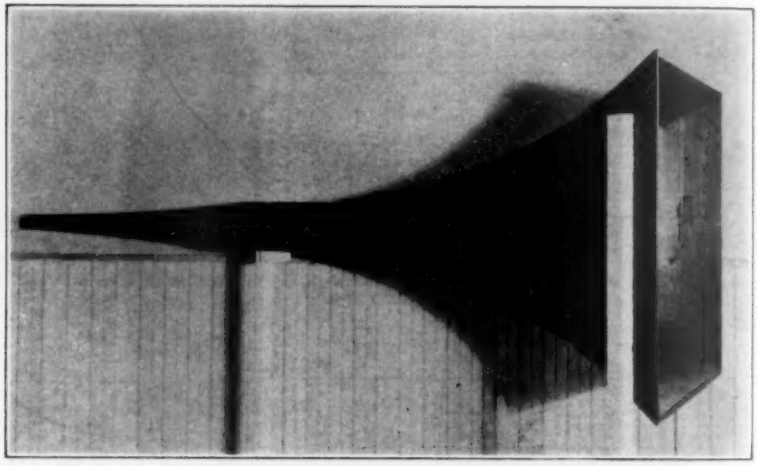


Frequency response curve. Comparison of 72-inch straight horn and same horn with initial 12-inch straight section.

from an electrical pick-up and power amplifier, is to be demonstrated later. This speaker employs a six-inch cone driven by an electromagnetic power unit. The volume and quality of this type of reproducing apparatus is most excellent. The complete apparatus is a development secured from radio experience and is one of the outstanding steps forward in the reproduction of sound.

A most valuable feature of electrical reproduction should be noted. It is possible to add a large amount of electrical energy

FIG. 22.



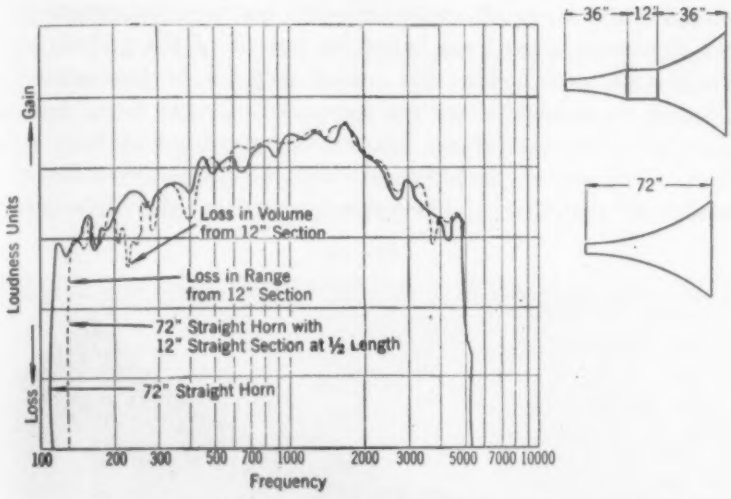
84-inch horn with 12-inch intermediate section.

to the mechanical energy picked up from the record and reproduce the sound with enormous amplification.

We have considered mechanical and electrical reproduction starting with the record groove and ending with the throat of the horn. It remains to discuss the general characteristics of various horns; certain of the factors entering into tone-chamber design will be indicated. Here the value of the response curves is clearly shown.

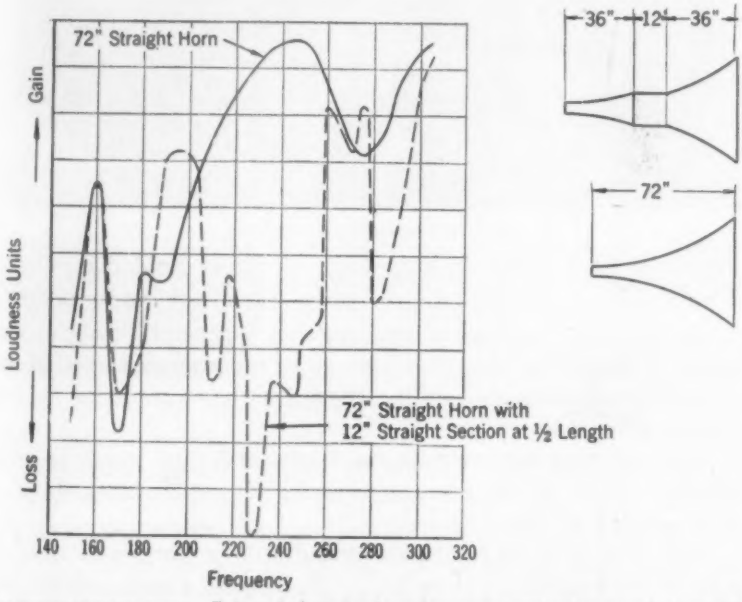
The first series of horns to be considered are straight horns 16, 32, and 72 inches long, respectively. (Fig. 16.) Each is designed to give a straight line response over its particular range and to show the necessity of using a large tone chamber for quality talking-machine reproduction. Each is balanced to the reproducer previously described.

FIG. 23.



Frequency response curve. Comparison of 72-inch straight horn and same horn with 12-inch straight section at ½ length.

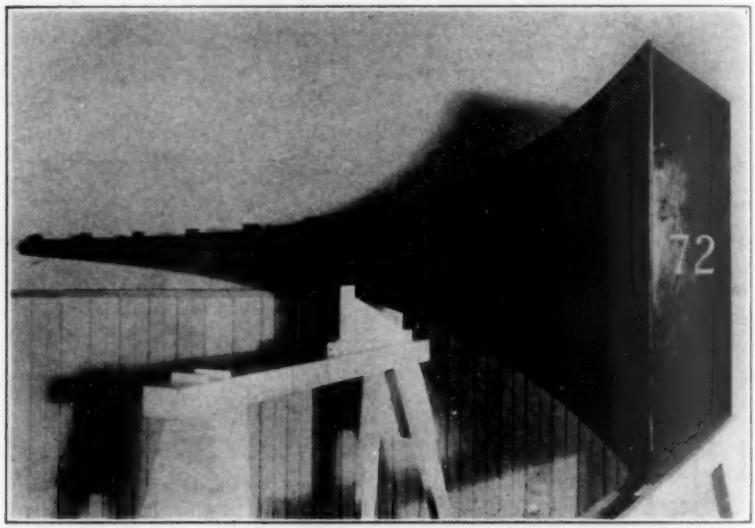
FIG. 24.



Frequency response curve. Enlarged view of volume loss at 230 cycles due to 12-inch straight section at ½ length.

One fact should be noted here. In a previous slide shown, indicating the range of various musical instruments, certain were seen to possess notes lying below the cut-off of the 72-inch horn. While pure tones below this cut-off will not be transmitted or radiated, no musical notes are composed of pure tones, and the tones below the cut-off are heard and recognized by their overtones. The more fundamentals, and the more overtones it is possible to reproduce in their true proportion, the more natural

FIG. 25.



72-inch standard horn with leaks.

is the tone color of the reproduction. A lower fundamental limit of 100 cycles covers the required range effectively, and a decrease in tone color or character of reproduction is perceptible above that range. This size of tone chamber can be incorporated in a cabinet of good proportions and utility. It leaves but little to be desired for any normal use.

We will first demonstrate the horns and then examine their response curves in order to see what the response curves show us about quality of reproduction.

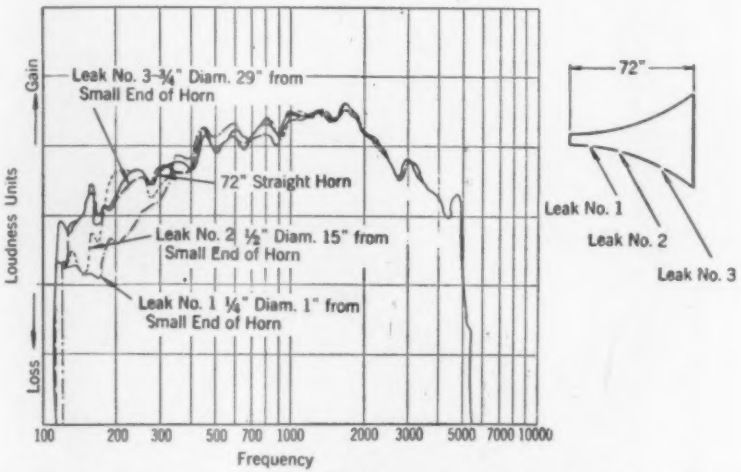
The first horn to be demonstrated will be the small straight horn 16 inches long. (Fig. 17.) Its general characteristics are absence of bass and resulting high pitch of reproduction. The

general character of the reproduction is unpleasant and lacking in naturalness.

The second horn to be demonstrated is the 32-inch straight one. The bass frequencies have increased and the reproduction is much more pleasant than that of the small horn. In actual truth this horn gives a reproduction about equal in naturalness to the best of the old-style phonographs.

The third straight horn 72 inches long will now be demon-

FIG. 26.



Frequency response curve. Comparison of 72-inch horn and same horn with three leaks. Leak No. 1, ¼-inch diameter, 1 inch from small end of horn. Leak No. 2, ½-inch diameter, 15 inches from small end of horn. Leak No. 3, ¾-inch diameter, 29 inches from small end of horn.

strated. As is evident, there has been a great increase in bass with a resulting breadth of tone and naturalness of reproduction which is superior to that of either of the other horns.

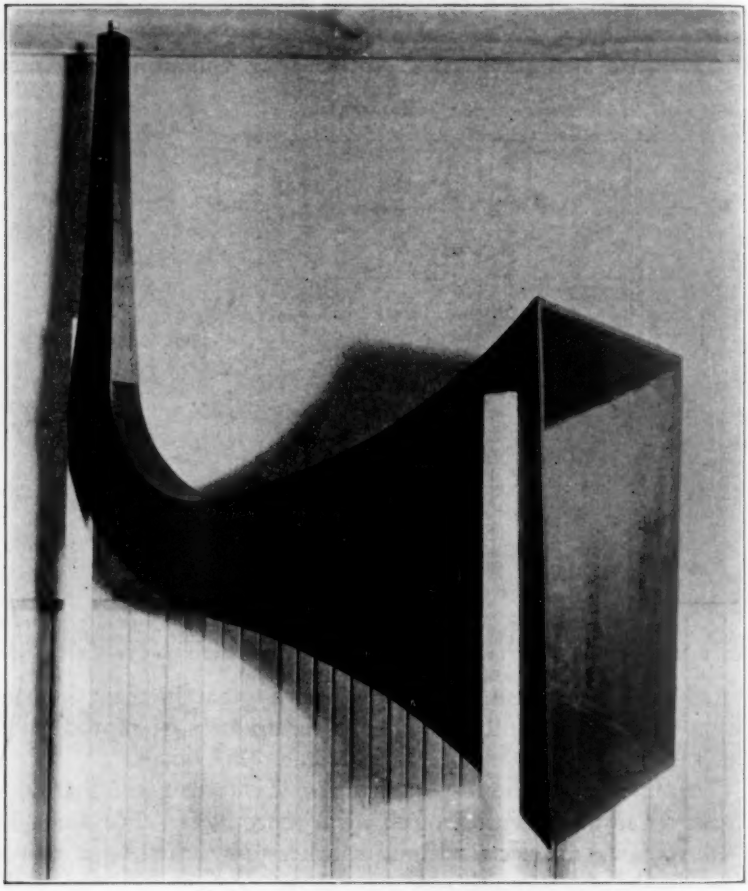
Turning now to the response curves, it is to be noted that none of them was made with a mechanical reproducer. For the sake of convenience an electrical loud speaker unit actuating a reproducer diaphragm was utilized.

This was operated under a constant voltage input from a vacuum tube oscillator over the desired frequency range and the sound energy output measured and plotted as previously described. It will be noted that the curves that follow are not horizontal; but have an upward, and then a downward slope. This is the result of room characteristics, in the lower frequencies; and electrical

unit characteristics in the upper frequencies. Factors of correction might well be applied, but would not have bettered the curves for purposes of comparison.

The curves of the three straight horns just demonstrated are

FIG. 27.

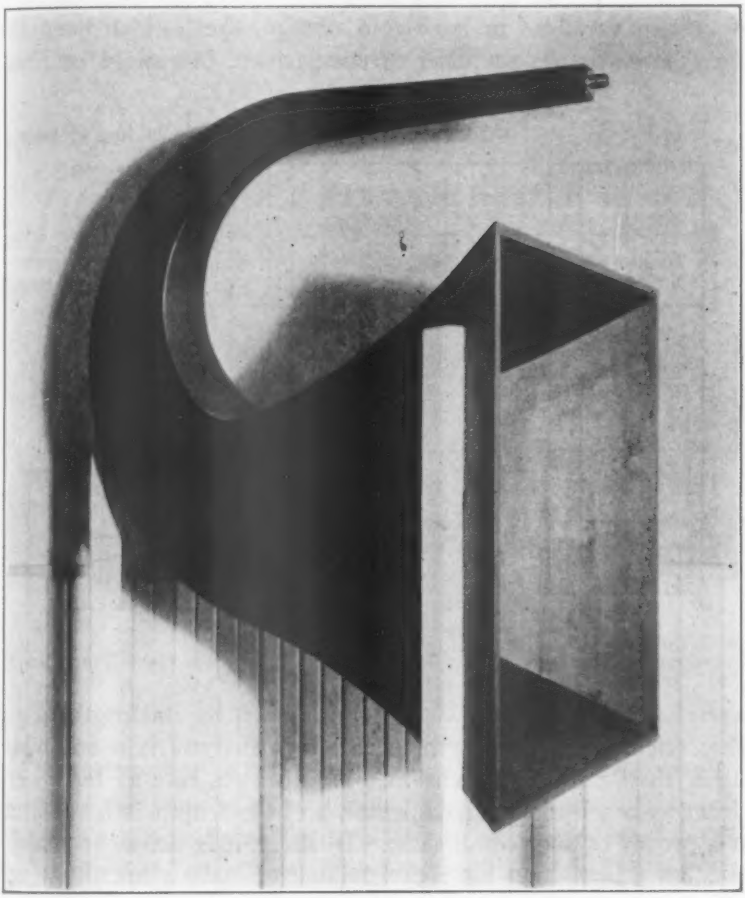


72-inch horn with 90° bend.

shown in Fig. 18. The first point to be noted is that there are no marked resonant points that would cause unpleasant or unbalanced reproduction. The second point to be noted is that the response curves agree almost absolutely over their respective ranges. The third point to be noted is the marked increase in horn size required

to extend the response downward over the musical range. If this were carried further a 9-foot horn properly designed would reach down to 80 cycles, a 13-foot horn to 60 cycles; a 20-foot horn to

FIG. 28.



72-inch horn with 180° bend.

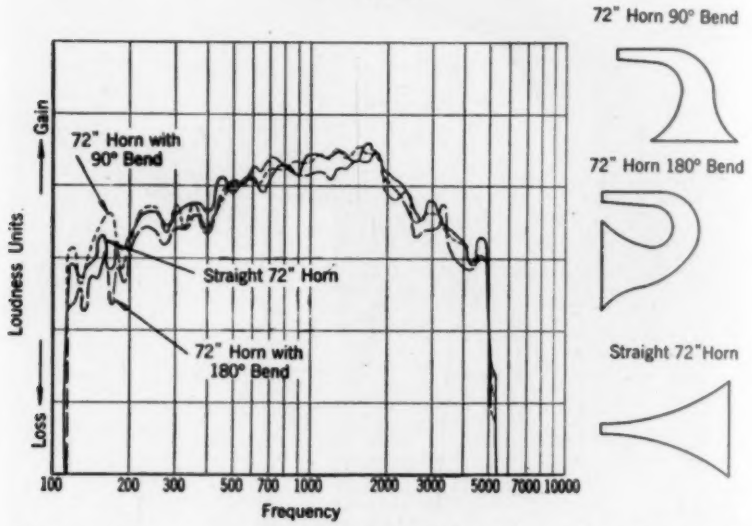
42 cycles and a 64-foot horn would be required to reach the lower limit of the musical scale.

That the response curves shown represent good reproduction can be understood when they are compared with these four curves which represent common reproduction. (Fig. 19.) These are

noted to be full of peaks and hollows of short range and the reproduction is characterized by shrillness, uneven loudness, general unnaturalness and poor balance. The amount of the musical range covered in the lower register is small.

In studying the performance of various horns, and the effect of certain variables in horn construction, the 72-inch horn has been chosen as the standard of comparison. It might be noted

FIG. 29.



Frequency response curve. Comparison of straight 72-inch horn and same horn with 90° and 180° bend.

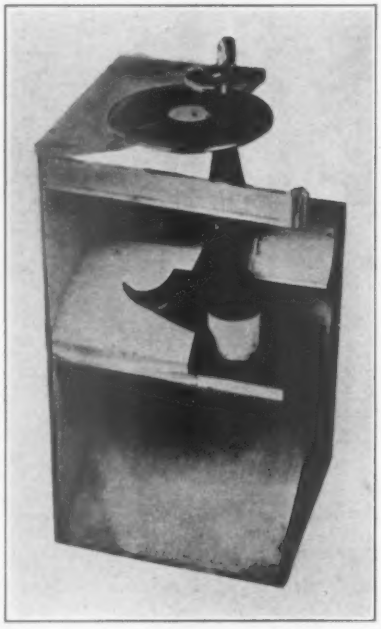
here that the custom of classifying a horn by its length is not truly scientific. The length in the final analysis is a secondary rather than a ruling dimension. Mouth area, rate of taper, and throat area are more fundamental, and the length is a resultant of a proper balance of all these. In short, it is simple to make a long horn, but somewhat more difficult to make a horn that will radiate any sound that reaches the mouth, without reflection, and give an even response down to its low-frequency cut-off.

Three horns, incorporating proper design features, and having low-frequency cut-offs of 350 cycles, 220 cycles and 113 cycles have been demonstrated. The effect of certain variables that may seem desirable or necessary on incorporating the largest of these horns in a talking-machine cabinet will now be demonstrated and

compared with the standard straight horn. The variables considered are: Addition of initial straight sections; addition of intermediate straight sections; air leaks in the sound passage, and effects of bends. Certain limitations of tone-chamber design are hereby indicated, as shown by the response curves, on comparison with a straight standard horn.

The first curves in the series are those of the standard 72-inch

FIG. 30.



A cut-away orthophonic Victrola tone chamber showing the folded sound passages.

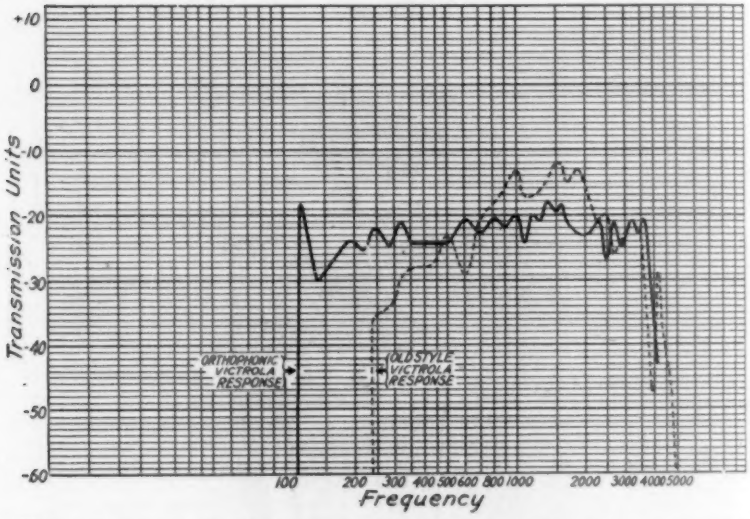
horn and this same horn with an initial straight section of 6 inches attached to it, bringing the total length up to 78 inches. (Fig. 20.) The full line is the standard and the dotted line the standard with the 6-inch straight section. The principal effect of the added section was felt in the bass frequencies, where it at first improved the response and then reduced it. It will be noted throughout that securing a balanced bass is a most difficult problem and unfortunately it is here that the character of a reproduction is established.

In the same manner as the 6-inch straight section, a 12-inch section was attached to the standard horn and the resulting curve

taken. (Fig. 21.) Its effect was the same as that of the 6-inch section, except that it was more exaggerated. In the lowest frequencies the response was greatly improved and then cut down to a marked extent as the frequency increased.

Instead of placing a straight section at the beginning of the standard horn, a 12-inch straight section was put in the middle

FIG. 31.

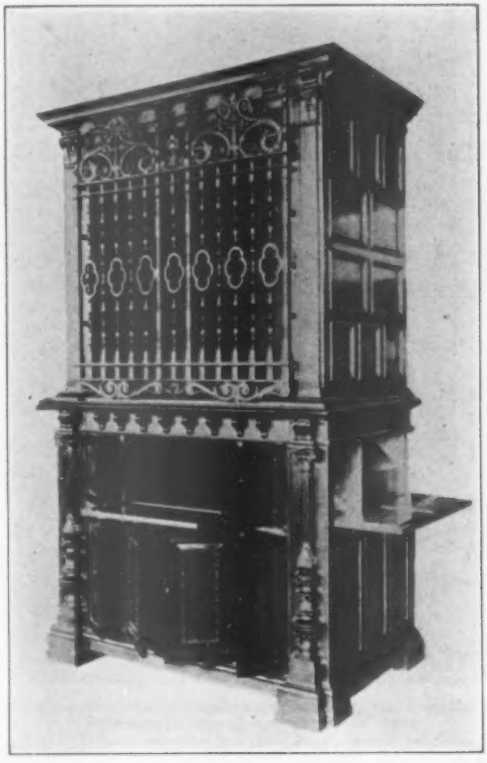


These response curves show the improvement of the new reproducing system, as compared with the old. Evenness and breadth of response are marked.

(Fig. 22) and a response curve taken. (Fig. 23.) Its effect was quite different from that obtained with a similar section at the beginning of the horn. It raised the cut-off point and appreciably reduced the range of the horn. In other words, the longer horn had a higher cut-off. In addition it produced a great reduction of volume at about 230 cycles. Fig. 24 shows an enlarged view of the reduction and the effect on the reproduction of a pure note of 230 cycles is marked when compared with the same note on the straight standard horn. This reduction of volume is not noticeable at other frequencies, as I will demonstrate. The effect of variations such as these is a reproduction that tires over a long period of time. A smooth, even response permits diminuendos and crescendos to be taken in recording, whereas these had to be avoided in the past, as they tended to reproduce with a tremolo.

The effect of leaks in the standard horn (Fig. 25) is well illustrated by these curves. (Fig. 26.) The size of the leaks varied from a ¼-inch-diameter hole to a ¾-inch diameter. The small leaks were placed close to the beginning of the horn in the high-pressure region. Curve 1 was produced by a ¼-inch-diameter hole 1 inch from the small end of the horn. As the distance of

FIG. 32.



A large horn is required to extend the proportion of the musical range of the instrument. Such horns can be best incorporated in the room structure. A complete instrument carrying a 13-foot horn is shown.

the leaks from the small end of the horn increased their effect decreased even though they were of larger area.

Two curved horns were also made, one with a 90° (Fig. 27) and another with 180° (Fig. 28) bend and responses taken on them. (Fig. 29.) The effect in both cases was to make the lower end of the range more erratic than that of the standard.

This was accompanied in the horn with the 180° bend by a reduction in response at the lower end of the range. This indicates a loss in efficiency of transmission of the longer sound waves around the curves even though easy curves are used.

From all of these curves the general conclusion can be drawn

FIG. 33.

A horn 20 feet long has been incorporated in an auditorium talking machine. This will radiate sound down to about 40 cycles per second.

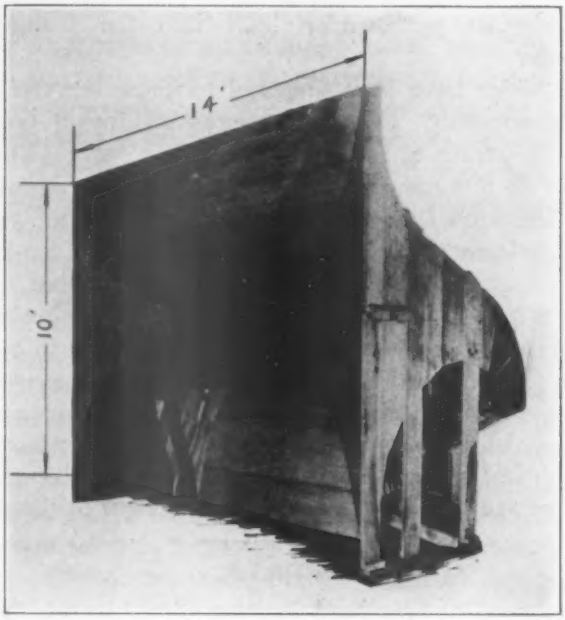
that any change in the design of a horn will produce a corresponding change in its response. It appears that most departures from the standard design are detrimental to the performance of a horn, but that some few are helpful. In placing the 72-inch horn in a commercial cabinet it has been necessary to make ten bends in the sound passage. (Fig. 30.) A method which obviously cannot be disclosed has been secured of making these bends without harming the performance of the horn. This is indicated by

the response curve taken of the commercial talking machine. (Fig. 31.)

The new recording and reproduction brings out the S-region in speech. The sibilants lie in the upper register, and aid much in rendering the reproduction intelligible and natural. In fact, the sentiment, the intelligibility and the definition lie in the upper register and the character in the lower.

Before demonstrating the recent developments by actual repro-

FIG. 34.



A forty-foot horn is here shown as an actuality, but in an experimental form.

duction, it would seem desirable to look a short distance into the future. Any marked advance in science is followed by a long period of intensive work. Refinements in detail, redesign to better meet production requirements, and a complete rechecking of the basic theory follow up the research work.

The old reproduction was frankly a method of producing sound conveniently, for education or entertainment. As such it met a definite need. The new reproduction is a truer reproduction of the original sound, and as such must meet much higher stand-

ards. Volume possibilities are present that necessitate a rigid adherence to design requirements. We need lighter and stiffer materials for reproducer parts, to attain even greater efficiencies. We will not be happy until even the smallest variations in the response are ironed out.

Because of the unlimited volume possibilities of the electrical reproduction, and with a desire to reproduce over even more of the musical range, research workers are now pressing the development of auditorium instruments. These have tone chambers beyond the limits of the commercial talking machine, and would of necessity be permanently built into the auditorium or music room.

Three slides have been prepared to show the trend of the present development. One illustrates an auditorium-type instrument incorporating a 13-foot horn. (Fig. 32.) The second (Fig. 33) is a somewhat larger instrument, designed by our Physical Research Department, and the third (Fig. 34) is the largest experimental horn built to date. These will handle almost any desired amount of sound energy, and yet radiate the sound so evenly that no sensation of overloading or distortion is present. The same energy applied to a smaller horn appears to produce an unpleasant and marked directional effect. Better response, and better radiation, with ability to reproduce large volume are the reasons for the development of the auditorium instrument. The theatre, moving picture show, the hotel banquet hall, and the rich man's home are logical places for an instrument of this type.

ERRATA.

"Inductance of Overhead Transmission Lines with Unequal Spacing of Wires," by Alfred Still, September, 1926, JOURNAL:

Page 366, 2nd word, 5th line, should read "reactive."

Page 367, 13th line from bottom, "Formula (1)" should read "Formula (3)."

Dyestuffs Industry.—A concise history of the dyestuffs industry has been written by R. E. ROSE (*Jour. Chem. Ed.*, 1926, **3**, 973–1007). The paper is copiously illustrated with pictures of the leading research workers in this branch of synthetic organic chemistry, with structural formulæ of typical dyes, and with fabrics dyed and pasted on the printed page. J. S. H.

THE THEORY AND DEVELOPMENT OF THE INTERPOLE MOTOR.*

BY

MALCOLM MacLAREN, E.E.

Chairman, Department of Electrical Engineering, Princeton University.

In preparing the paper of this evening I have departed somewhat from the subject assigned to me and have enlarged its scope so as to trace the development of the direct-current machine in general, showing how the theory of its operation emerged from the crude conceptions of one hundred years ago and how increased knowledge led to improvements which culminated in the interpole construction of the modern machine. With this as a background I would like to consider broadly some of the problems of design, showing how general proportions may be selected and illustrating the application of these principles by reference to some recent typical installations.

Two great fundamental discoveries lie at the basis of the operation of all so-called "dynamo electric machines." The first of these is that the passage of a current through a conductor produces a magnetic field around the conductor, this fact being utilized in the production of the field system of the machine. The second discovery is really the converse of the first, namely, that the movement of a closed circuit into a magnetic field will cause a current to flow in the conductor, or more broadly, that any movement of a conductor in a magnetic field will cause an electromotive force to be generated in the conductor. This fact is utilized to obtain the voltage at the armature terminals as the armature conductors rotate across the face of the poles.

The development of the modern dynamo may, therefore, be said to date from the year 1820 when Oersted discovered that a magnet needle was deflected when a current was set up in a neighboring conductor. This was a period of great activity in the study of electricity and magnetism and immediately following Oersted's discovery, Arago and Davy showed that iron filings adhered tenaciously to a conductor carrying a current. At the same time Ampère made his famous experiments which proved the equivalence of the closed electric circuit and the magnetic shell.

* Presented at a meeting held Thursday, February 25, 1926.

He also intensified the magnetic action of the straight conductor of Oersted's experiment by bending it first into a loop and then into a succession of loops to form a solenoid. Arago utilized the solenoid to magnetize steel needles and in 1825 Sturgeon produced his electromagnet by winding a helix over an insulated iron rod bent into the shape of a horse-shoe. Finally, in 1830, Joseph Henry took the last step in the development of the electromagnet as we have it to-day by the simple expedient of insulating the wire of the exciting coil instead of the magnet itself. There is a tradition in Princeton that he used for his insulation his wife's discarded silk skirts. However that may be, he was able with his construction to increase greatly the strength of his magnets and by properly proportioning the resistances of his exciting coils to the batteries at his disposal, he demonstrated to the astonishment of the scientists of his day the tremendous forces which might be developed by his device.

Experimenters were quick to seize upon Oersted's discovery as a means for producing motion and we see the development of Barlow's wheel and Faraday's rotating wire loops. Probably the most vigorous action produced by these means during this period was due to Henry. He pivoted an iron bar above the poles of permanent magnets and magnetized the bar by a coil which was connected to a battery through mercury cups, the terminals of the coil being so arranged that the movement of the bar caused its polarity to be reversed, thus producing a reciprocating motion. He claims for his device rather more originality than appears to be justified when he describes it as follows:

"I have lately succeeded in producing motion in a little machine by a power which I believe has never before been applied in mechanics—by magnetic attraction and repulsion. The motion here described is entirely distinct from that produced by the electromagnetic combinations of wires and magnets; it results directly from the mechanical action of ordinary magnetism, galvanism being used only for the purpose of changing the poles."

He acknowledges, however, that the action would be intensified if electromagnets were substituted for his permanent magnets, but does not claim that even then the device could be considered as a practical means for producing power. Before this could be accomplished, it was necessary that the results of Faraday's great discovery of electromagnetic induction should be developed.

As early as 1824 Faraday definitely set himself the problem of proving experimentally that the action discovered by Oersted was reversible and that the movement of a conductor in a magnetic field would produce a current. It was not, however, until 1831, after seven years of patient research, that he was able to announce his discovery. It is hard to picture the difficulties under which these early investigators were laboring without the use of any electrical measuring instruments except a crude form of galvanometer. Some indication of the situation may be gained from the following extract from a paper written by Joseph Henry in the *American Journal of Science* of July, 1832, immediately after the announcement of Faraday's success reached America.

"Although the discoveries of Oersted, Arago, Faraday, and others, have placed the intimate connection of electricity and magnetism in a most striking point of view, and although the theory of Ampère has referred all the phenomena of both these departments of science to the same general laws, yet until lately one thing has remained to be proved by experiment, in order more fully to establish their identity, namely, the possibility of producing electrical effects from magnetism. It is well known that surprising magnetic results can readily be obtained from electricity, and at first sight it might be supposed that electrical effects could with equal facility be produced from magnetism; but such has not been found to be the case, for although the experiment has often been attempted it has nearly as often failed.

"It early occurred to me, that if galvanic magnets on my plan were substituted for ordinary magnets, in researches of this kind, more success might be expected. Besides their great power, these magnets possess other properties, which render them important instruments in the hands of the experimenter; their polarity can be instantaneously reversed, and their magnetism suddenly destroyed or called into full action according as the occasion may require. With this view, I commenced last August the construction of a much larger galvanic magnet than, to my knowledge, had before been attempted, and also made preparations for a series of experiments with it on a large scale, in reference to the production of electricity from magnetism. I was, however, at that time accidentally interrupted in the prosecution of these experiments, and have not been able since to resume them, until within the last few weeks, and then on a much smaller scale than

was at first intended. In the meantime, it has been announced, in the one hundred and seventeenth number of the *Library of Useful Knowledge*, that the result so much sought after has at length been found by Mr. Faraday, of the Royal Institution. It states that he has established the general fact that when a piece of metal is moved in any direction, in front of a magnet pole, electrical currents are developed in the metal, which pass in a direction at right angles to its own motion, and also that the application of this principle affords a complete and satisfactory explanation of the phenomena of magnetic rotation. No detail is given of the experiments, and it is somewhat surprising that results so interesting and which certainly form a new era in the history of electricity and magnetism, should not have been fully described before this time in some of the English publications."

Henry then proceeds to describe an experiment which he made with his electromagnet to demonstrate the phenomena of mutual induction which he states was made before he had any knowledge of the method Faraday used in his experiments. It is evident from this that he shares with Faraday the honor of independent discovery of mutual induction. He carried his investigations further and is known to be the first to have discovered the phenomenon of self-induction. To Faraday, however, belongs the unique distinction of being the first to produce a continuous current by the rotation of a conductor in a magnetic field and thus may rightfully be considered the originator of the modern direct-current generator. To be sure his device was very crude, consisting of a small copper disc rotated between the poles of a permanent magnet with sliding contacts resting on the shaft and the rim of the disc, and yet the essential elements of the modern generator were present in this device. By means of these experiments Faraday was able to give a completely satisfactory explanation of the operation of Barlow's wheel and show the reversibility of its action. The significance of this for the transmission of electric power was not recognized, however, until many years later. In fact, the great possibilities which were opened up by these discoveries apparently failed to be appreciated by any of the early investigators. Henry's statement quoted above indicates that they were endeavoring to prove the identity of electricity and magnetism and they appeared to be satisfied that Faraday's experiment provided this proof.

During the decade following Faraday's work, a coil of wire was substituted for his copper disc, and when rotated between the poles of a permanent magnet gave an alternating current, then a two-part split-ring commutator was added to produce a rectified pulsating current and in 1840 Wheatstone devised a rotating element having several coils, the terminals of each being connected to its own split-ring commutator and these were connected together so as to give a fairly uniform current in the outside circuit. In 1845 he improved his device by the substitution of electromagnets for his original permanent magnets. He obtained a patent for this, although Jacobi appears to have used much the same arrangement in 1838. During the next decade we see the first indications of the development of self-excited generators in which a combination of permanent and electromagnets was used. But this received little attention until 1866–1867 when Siemens, in Berlin, Wheatstone and Varley, in England, and Farmer in this country almost simultaneously and certainly independently found that self-excitation could be obtained without the use of permanent magnets, but by- means of residual magnetism. Siemens apparently used a series connection between his field and armature and therefore obtained an unsteady voltage, and Wheatstone and possibly Varley used a shunt-connection. The latter in 1878 brought out his compound-wound machine and was among the first to use this combination.

Little progress was made in the development of the armature of the electric generator between the years 1840 when Wheatstone brought out his multicoil and split-ring combination, and 1856 when Siemens produced his shuttle-wound armature. This had a single coil and the original machine was an alternator. This design was, however, later modified to produce direct current and marks a distinct advance in two particulars. First, it was a true drum type of armature which was developed so effectively by later designers to the practical exclusion of other forms for direct-current machines, and secondly, the winding was placed upon an iron core and a small air-gap was used between core and poles, thus giving a lower reluctance for the magnetic circuit than in any of the previous designs.

The year 1860 marks a real epoch in the development of the art, for in that year Pacinotti constructed his machine, which possessed a number of unique features. His armature was ring

wound with a multiplicity of coils, each being led to a separate commutator bar. The coils were wound in slots in the armature surface. He used broad pole faces covering about 75 per cent. of the armature surface and employed a small air-gap. He designed his machine primarily for a motor and used electromagnets for his field, having the coils connected in series with the armature. He explained, however, that the machine could be run equally well as a generator provided the excitation was started by placing a permanent magnet near the armature or by separately exciting the field from a battery. To Pacinotti belongs the distinction of being the first to use the slotted armature, the ring winding and the multi-segment commutator and yet his designs attracted little attention at the time, and when Gramme began his investigations ten years later, he apparently had no knowledge of Pacinotti's work.

Gramme rediscovered the ring winding and introduced one marked improvement over Pacinotti's form in using an iron wire core for his ring in place of solid material, thus reducing the losses and heating in the armature. Gramme's first machines had permanent magnets and were quite small affairs driven by hand, through reducing gears. A later form was mounted upon a frame and was operated by foot-power. Then in 1872 he adopted the use of electromagnets and began manufacturing upon a really commercial basis, turning out machines which were used for arc lighting or electroplating. During that year he built ten machines of one pattern. These had two armatures and field systems, one of which was used to excite the fields of the other, which in turn operated an arc light. Then he built a two-light machine having three armatures. This design was soon modified by omitting the exciter and using a double-wound armature in a single self-excited field. Finally in 1873 he developed the machine having a simple ring-wound armature which we associate with his name. This is recognized as being the first really commercial direct-current generator to be produced. It is the first of which we have any record which could operate at a reasonable load for long periods of time without overheating and without serious sparking.

Gramme exhibited two of these machines at the International Exhibition in Vienna in 1873, operating one as a generator to drive the other as a motor and thus gave the first public demonstration of electric power transmission. He made the same

exhibit here in Philadelphia in 1876 at the Centennial Exhibition which attracted wide attention. At the close of the Exhibition, Prof. C. F. Brackett purchased one of these units for Princeton University and for years it was submitted to the hard usage of the laboratory without any apparent deterioration. Lately we have placed it in honorable retirement in our Museum. It would be interesting to know whether its partner found its way to the scrap heap or is receiving like recognition.

The work of Gramme may be considered as closing the pioneer period of this development. The tremendous advance that has taken place during the last fifty years has been due largely to improvements in mechanical details, to a better understanding of the use of materials and above all to improved methods of commutation.

The armature coil in the Gramme ring had inherently high reactance, as it consisted of many turns which surrounded the magnet core of the armature. Successful commutation was obtained by keeping down the current output and by a careful setting of the brushes which had to be shifted with every change in load. Then the drum type of winding began to gain favor in which the conductors lay on the surface of the armature. This gave a lower reactance and was easier to wind, but difficulties were experienced in holding the coils in position, especially with multipolar machines. It was largely for this reason that slots were cut in the armature surface. In recognition of the origin of this design many early writers referred to these as "Pacinotti slots." The advantage of the small air-gap resulting from this construction was also understood, but now new difficulties were encountered in the heating of the pole faces, due to the bunching of the flux at the top of the armature teeth. When modifications were made in the shape of the slots to overcome this defect, surprises and disappointments often followed. I recall a large generator in which the slots were completely closed at the top. The machine sparkled viciously at almost any load, but fortunately the trouble was completely cured in this case by cutting narrow openings at the top of each slot. It was through experiences of this character that designers gradually came to an understanding of the effect of slot proportions upon commutating characteristics.

During the decade from 1880 to 1890 considerable ingenuity was shown in devising a great variety of forms for two-pole

machines, each designer apparently following out some theory of his own rather than basing his design upon sound engineering principles. By the end of the period, however, the laws of the magnetic circuit were pretty generally understood and the advantages of using the multipolar construction for the larger sizes was appreciated. But the outstanding contribution which this period made to the development of the direct-current machine was the introduction of the carbon brush. This was unquestionably the controlling factor which made possible the tremendous advance in electrical engineering which started during the next decade. In 1885 Prof. George Forbes obtained a patent for the carbon brush and sold his American rights to the Westinghouse Company. The patent itself did not seem to possess much value, for we soon find the carbon brush being used freely by others, notably by Sprague in 1887 for his railway motors for the Richmond trolley installation. From the technical press of the period it would seem that designers were almost apologetic when they suggested the use of carbon brushes and only employed them as a last resource. At first they were confined entirely to motors subject to sudden wide fluctuations in load, where it was impracticable to shift the brushes.

It is not surprising that these early designers hesitated about abandoning brushes which could carry 250 amperes per square inch at the surface of the commutator for high-resistance brushes limited to about one-fifth of this value, especially as station operators of those days took it for granted that they must shift brushes with changing load. This was not much of a hardship when units were small and loads were fairly steady. The worst that could happen would occur when the load was thrown off suddenly by the burning of a fuse or the opening of a circuit breaker. Then there might be considerable fireworks while the attendant was getting the brushes back to neutral, which might even necessitate the renewal of the brushes before service could be reëstablished.

Reference has already been made to the fact that one of the first applications of the carbon brush was to railway motors. The problem of the railway generator taxed designers even more severely for there was added to the difficulty attendant upon the fluctuating character of the load and the high voltage, an increasing demand for larger capacities. Early experience in

the development of such machines led to the adoption of the carbon brush and the improved performance was so marked that this form of brush soon came into general use.

In view of the epoch-making character of this development it might be well at this point to refresh our memories regarding the reasons for this extraordinary improvement in performance. It is well understood that with the metal brush the short circuit of the coil under commutation is so complete that at the moment the leading commutator bar (in the case of a generator) breaks contact with the brush, the current tends to jump instantly from zero to the full value of the current in the active part of the circuit, self-induction retards this change and the current finds a freer path across the commutator surface, thus producing sparking. By giving the brushes a forward lead so that an electromotive force is induced in the short-circuited coil equal and opposite to the electromotive force of self-induction, the current is reversed during the short-circuit and no sparking occurs. A very careful adjustment, however, is necessary, which changes with the load, consequently requiring a shifting of the brushes. With the high-resistance carbon brush, on the other hand, the variable resistance of the contact between the brush and the commutator as the commutator bar moves across the brush, forces a change of current in the short-circuited coil which, even with comparatively high self-induction, produces a complete reversal of current by the time the brush breaks contact with the bar, thus giving sparkless operation. Relieved of the necessity of obtaining an accurate neutralization of self-induction, it is possible with the carbon brush to give a considerable forward lead at no load and obtain satisfactory performance in the same position at 25 to 50 per cent. overload. Or, by using somewhat lower self-induction and working with a stiffer field, it was possible, as in the case of the early non-interpole railway motor, to obtain fair commutation with the brushes fixed on the neutral point. Carbon brushes also kept the surface of the commutator in better condition than was possible with metal brushes. This was partly due to the lubricating action of the brush and also because the volatilization of the carbon when sparking did occur would not injure the surface to the same extent as similar conditions with metal brushes.

These improvements in design quickly led to wide application of direct-current motors for industrial purposes and for the

operation of trolley lines and railways. The period from 1890 to 1900 was a time of great activity in developing standard lines of motors and generators to cover a wide range of capacities, voltages and speeds, and practically all demands of the market could be met without departing radically from conventional types. The ingenuity of designers was largely extended in perfecting the mechanical features of his designs and in devising improved methods of ventilation.

There was one notable advance in design during this period which fundamentally affected performance, namely, the use of cross-connecting rings with multiple-wound armatures. It had been found by experience that 250 amperes was about the maximum steady load that could be commutated satisfactorily in an armature conductor. The series type of winding which has two paths through the armature was therefore limited to machines whose rated output did not exceed 500 amperes. As the demand for larger sizes developed and the attempt was made to subdivide the current in multiple windings, many failures were recorded, but a complete cure was found in the use of cross-connecting rings. These are tapped into the winding at equipotential points and the number of rings is so chosen that not more than four or five commutator bars intervene between taps. The function of these rings is to equalize the electromotive forces in the different groups of armature coils when inequalities exist in the flux of the individual poles. This is accomplished when such inequalities are present by currents which circulate through the armature conductors and cross-connecting rings in such a direction as to weaken the stronger poles and strengthen the weaker. The results have proven so satisfactory that these rings are now considered an essential part of a multiple winding.

With the opening of the present century new conditions arose which appeared to call for radical changes in design. The steam turbine had been successfully employed for driving alternating-current generators, and a demand was created for direct-current generators for similar service operating at speeds far beyond anything attempted up to that time. Also with the growth of power systems it became more economical to abandon generation at the point of consumption in favor of alternating-current generation and distribution to sub-stations. When motor generator sets were used to convert to direct current, the speed of the set was

limited by commutation on the direct-current side and considerable pressure was placed upon the designer to reduce costs by devising methods for commutating satisfactorily at higher speeds. Also a growing demand developed for motors operating at a wide range of speed. These three classes of service all demanded the raising of the speed limit at which successful commutation could be obtained. Probably more talent was expended and a greater number of failures recorded in attempting to develop the direct-current turbo-generator than in any other class of electrical apparatus, and the final solution except for small units was to dodge the issue by coupling to the steam turbine through gearing which permits each side of the unit to be designed for its most economical speed.

These early attempts to design a satisfactory turbo-generator in spite of many disappointments yielded useful results in that it taxed designers to the utmost and led many to study the characteristics of interpole construction. This was not a new device, for in 1888 Swinburne proposed this type and built several machines with different forms of interpoles. But with the two-pole machines of his day, there were mechanical difficulties in the way of properly setting his interpoles and he did not meet with much success. Then in 1894 the Thompson-Ryan interpole machine was brought out, but this design did not receive any general recognition, largely because the requirements for direct-current machinery of that period could be met with the more familiar non-interpole type. Ten years later the situation had changed and experience with turbo design demonstrated the advantages of interpoles and they came into general use first for high-speed and adjustable speed machines and then for practically all classes.

The interpole produces a field at the neutral point midway between the main poles and being energized by the main armature current the strength of this field can be so adjusted as to automatically produce with varying loads an electromotive force in the coil under commutation equal and opposite to that of self-induction. This result is obtained with a fixed position for the brushes. Owing to difficulties in completely controlling the distribution of the interpole flux, it is not possible to entirely ignore self-induction, but it has been found that values can be increased to over three times the limit permissible with non-interpole machines. This does not mean that speed limits can be trebled, for other

factors enter in to limit this, but this improvement has led to much higher speeds, wider speed adjustment, higher voltages and much larger capacity units.

The question naturally arises of why should the design be complicated by the introduction of interpoles for the great majority of cases which would previously have been handled successfully without interpoles. This reduces itself to a matter of cost, and it is easy to show that a considerable saving in material will result by the use of interpoles. For in the first place raising the limit of self-induction permits narrower and deeper armature slots to be used, which provides more space for carrying the flux or provides the same space with smaller armature dimensions. Also the fixed position of the brushes allows the use of a relatively much weaker field. The two factors taken together permit a complete readjustment of the magnetic circuit with a considerable net saving in material even after allowing for the interpole system.

The effect of armature reaction upon the magnetic system had been noted in the early development of the machine and many attempts were made to minimize this action or to utilize it to advantage. One of the objects Swinburne had in mind in the use of interpoles was to set these with a backward lead in generators and thus improve voltage regulation by means of armature reaction. A number of more or less ingenious methods were proposed for controlling the distorting action of the armature. The use of a relatively strong field was recognized as an effective means for doing this, and the advantage of high saturation in the armature teeth and pole tips was understood. In the Thompson-Ryan machine mentioned above, complete neutralization of armature distortion was affected by placing conductors in slots across the pole face, connecting these in series with the armature and so proportioning them that the fields produced by the two systems of conductors cancelled each other. At first this construction did not meet with much favor, but with the more general use of interpoles, especially in the study of motor performance with very weak field as required for adjustable speeds, the advantage of the compensated field winding was demonstrated and the final step was taken in the development of the modern interpole motor, by combining these two types of construction.

Experience with the compensated winding with adjustable speed motors soon led designers to apply the same construction

to other types and at present there are indications that it may eventually be used for most classes of service. The justification for its general use arises from the fact that it produces a large reduction in the magnetic losses in the armature, as these are a function of the maximum flux through which each element has to pass, and this is reduced by the elimination of armature distortion. Also with complete control of the polar flux, it is possible to operate with a weaker field and so economize material.

Having traced the history of the development of the interpole machine, let us now consider some of the problems which the modern designer has to face in preparing plans for a specific case.

It is not my purpose to present methods for carrying out detailed calculations upon the design but to give a more general treatment. An inspection of the various text-books upon this subject shows the widest possible variation in procedure, ranging from the crudest sort of empirical methods to the most involved theoretical determinations. There appears to be a tendency for European designers to use more elaborate methods than is common in this country. Personally, I am a strong believer in the use of simplified formulæ and short cuts where the errors so introduced are well within the limits of tolerance which must be allowed for variations in the quality of material and in workmanship. Expressions which accurately represent conditions should of course be used if their application in a given case does not consume an undue amount of time. But it is not desirable, for example, to work through elaborate determinations upon the resistance of an armature conductor to an accuracy of .1 per cent., if a shorter method would give this within 1 per cent., in view of the fact that variations of this magnitude may occur in the conductivity of the material itself and no particular advantage is gained in this case in obtaining greater accuracy. Still greater latitude may be permitted in the calculations upon certain portions of the magnetic circuit, for variations of 10 per cent. must be expected in the permeability of such material and variations in workmanship must also be taken care of by providing margins of safety to enable proper performance to be obtained even with such irregularities. Fortunately in the case of the magnetic circuit most of the ampere turns are taken up in the air-gap where the permeability is always unity and quite accurate methods have been devised for the determination of the characteristics of this

part of the circuit, so that as a general thing the predetermined magnetization curve for the machine as a whole should check closely with test results.

When advocating the use of approximations I do not mean that inaccurate or careless work should be tolerated and having once settled upon a method this should be followed rigidly. One of the most important functions of these calculations is to enable the designer to decide upon the relative merits of several alternatives, and if the same method of calculation is employed throughout a very accurate determination of their relative characteristics can be made, although some departure from theoretical results may be expected in actual performance. The slide rule will give sufficient accuracy for work of this character, so that it would be uneconomical of time to use logarithm tables, or exact arithmetical determinations.

The first problem which confronts the designer is how he is to obtain the general proportions which should be adopted in the construction of a machine to meet a given set of conditions. This may be a very simple matter for a commercial designer in a large manufacturing establishment, for all that he has to do is to refer to his card index and find the machine which approaches most closely to the one under consideration and then determine how this should be modified to meet the new conditions at minimum cost. There the question of what will lead to a minimum cost may be quite complicated, but in any event a special effort must be made to minimize the number of dies, patterns and drawings required for the new design and this imposes special limitations in the design which are in no sense inherent in the machine itself. The importance of these considerations becomes less as the number of machines of the new design to be produced increases, but the matter of cost must always be kept in mind. It is a comparatively simple problem in most cases to produce a design which would show satisfactory performance. But this becomes quite an unimportant detail unless a second requirement is met, namely, that the machine can be produced at a cost which will meet competition and allow the product to be sold. It is only in the rarest cases that the matter of first cost does not have a controlling influence upon design. It may be that the time required for delivery is the predominating factor. I recall the case of a rush order where it was necessary to build up the design

of a machine around a certain size of commutator bar which was known to be in stock. Other similar limitations may be imposed in particular cases. For these reasons it is not safe to take the design of a commercial machine as a model of excellence unless the history of its development is known.

While this problem of obtaining the general proportions to use in a given case may be a simple matter to the experienced designer, it presents real difficulties to others, especially to the student who approaches the subject for the first time. A number of formulæ and economic coefficients have been proposed for assistance in such cases, but probably no single set of rules could be devised which would have general application. For traction and certain other types of drive, mechanical limitations have a controlling influence upon design. For small machines the problems of heating and commutation are much less severe than for large machines and quite different factors can be used. The following method for making preliminary determinations has been used successfully with students for a number of years and it has the advantage, I believe, of keeping the physical picture of the problem more clearly before the student than is possible if results are obtained largely by substitution in mathematical formulæ. While this method may not be general in its application, it may be employed for motors or generators for capacities from about 100 kw. upwards and for cases where there are no unusual mechanical or commutating difficulties. The starting-point in this case is the selection of the peripheral speed. This should be taken between 2500 and 3500 ft. per minute for slow-speed machines, 4000 and 6000 ft. per minute for moderate speeds, and 7000 ft. per minute and upward for high speeds. Then we must decide into which class a given machine will fall and this is a function both of speed and output. For instance a 100-kw. machine at 300 r.p.m. would be rated as slow speed, but a 1000-kw. machine at the same speed would fall into the intermediate class. It is entirely feasible to construct a graph connecting revolutions per minute, rating and peripheral speed for the ideal case, but it is unnecessary to go to this refinement as a margin of 10 per cent. should be allowed in either direction from this ideal, as it is possible to develop good alternative designs for a given case where the armature diameters may differ by as much as 20 per cent. It is not necessary, therefore, to arrive at a theoretically correct

diameter, especially in the first roughing out of the proportions. Later determinations will lead to more exact conclusions in this respect. Therefore with a little practice the student will be able to properly place a machine in one of the three classes given above and determine a reasonable diameter for trial.

The next step may be applied more rigidly, for it will be found that good general proportions will be obtained if the armature ampere turns, at full load, approximate 1200 per inch diameter of armature. Therefore having settled upon the peripheral speed and consequently the diameter of armature, the number of armature ampere turns that should be provided can be found by multiplying the armature diameter in inches by 1200. It is then possible to select the number of poles, for it is desirable to keep the armature ampere turns per pair of poles somewhere between 16,000 and 20,000. There again some latitude must be allowed for equally good designs may be developed in which the number of poles are different. Other factors enter in at this point which have a decided bearing upon the selection of the number of poles, namely, the current per armature conductor and the voltage between commutator bars. The maximum limit for the current has been raised from about 250 amperes per conductor for non-interpole machines to more than double this value with interpoles. The maximum potential between commutator bars should be kept below 22 volts.

This brings up the question of what type of armature winding should be employed. We recall the multiplicity of types of winding shown in early text-books. There were the ring and the drum types with singly, doubly and triply reëntrant connections and several other unclassified forms thrown in for good measure. Many of these were never used commercially and at present only two types are employed at all extensively. All forms of ring windings were abandoned years ago for mechanical if for no other reason. Furthermore, if the multiplying of windings is found to be desirable in any case, it can best be accomplished by a proper selection of the number of poles rather than through the brushes as with the old forms of reëntrant windings. It is therefore a general practice to use the series or wave type of drum winding for machines which have a rating of less than about 1000 amperes and the multiple or lap type when the current output is greater than this. In the series winding there are always two

paths for the current irrespective of the number of poles, while in the multiple winding there are as many paths as poles. The latter type is therefore generally used for large outputs and the number of poles is selected to keep the current per conductor at full load below 500 amperes. Cases may arise, however, where it will be found with the series winding, even when the current is well below the maximum limit, that not enough commutator bars can be employed to keep the maximum potential between bars below 22 volts, and that with the multiple type more commutator bars would be required than is desirable. For such cases a series-multiple type may be employed in which there may be four or more even numbers of paths irrespective of the number of poles. These are modified forms of reëntrant windings made practicable by the use of cross-connections. They are, however, more sensitive in their operation than either the straight series or multiple types and are to be avoided if possible.

Having then determined provisionally the armature diameter, the armature ampere turns, type of winding and the number of poles, the current per armature conductor is obtainable and consequently the number of armature conductors. It is then possible to apply the flux formula to determine the flux per pole and from this the general proportions of the pole itself. The area of the pole face should be selected to give a flux density at this point of approximately 60,000 c.g.s. lines. The width of the pole face should be slightly less than 70 per cent. of the pole pitch, and the other dimension of the pole along the armature axis is then selected to give the required area.

At this point it is possible to obtain a further check upon the armature diameter which has been provisionally selected for the ideal section of the pole is a square. In slow-speed machines the width of pole may be somewhat less than the dimension in the direction of the armature axis, while the reverse may occur for high-speed machines, but if the pole section departs widely from a square, it suggests that it would be advantageous to change the armature diameter or the number of poles.

The next step is to group the armature conductors into a reasonable number of slots. If less than fifteen slots per pole are used, injurious flux pulsations may be produced, and if more than about twenty-four slots per pole are employed, an uneconomical use of material results. The dimensions of the slot are next

determined, and as this is a factor which has a pronounced effect upon commutation, it has to be considered with great care. The first step is to select a proper cross-section for the armature conductor. This should, of course, be made no larger than necessary to carry the rated current with a temperature rise not exceeding prescribed limits. This in turn is a function of the combined loss in the conductor itself and the surrounding magnetic material and of the radiating capacity, all of which are subject to later calculations. If, however, a cross-section is selected provisionally between the limits of 2000 amperes per square inch for low peripheral speeds to 3000 amperes per square inch for high peripheral speeds, little alteration need be made when the final calculations are worked out. Having selected the cross-section of the conductor and the number of conductors per slot, the dimensions for the conductor should be so chosen that the depth of slot should not be too great, which would result in high reactance voltage or too wide, which would lead to flux pulsations, magnetic saturation and high losses. The slot depth should in most cases be between the limits of 1½ and 2½ inches and the slot width should be determined by the ratio of width divided by the slot pitch. This should fall between .3 and .35 for high-speed machines and .35 and .4 for slow speeds. If these limits are not obtainable, the armature diameter should be adjusted until they are reached. The commutating characteristics should now be determined and it may be found necessary again to make adjustments in slot proportions, armature length or diameter or in extreme cases in the number of poles to decrease the current per conductor and so obtain satisfactory commutation.

The methods used for predetermining commutating characteristics can be considered at this time only in a very general way. The first step is to determine the reactance voltage of the coil under commutation. The complete solution of this involves the use of very complicated formulæ, but quite simple empirical expressions can be substituted in most cases with satisfactory results. In addition to the reactance voltage, the shape and dimensions of the interpole, the characteristics of the path for the interpole flux, the width and character of the brush, the width of commutator bar and the ratio of field to armature ampere turns all have an important bearing upon commutation. The limits which can be used in each case are well understood and the

experienced designer can now quite definitely predetermine performance in a given case.

By the use of interpoles, the problem of commutation has been so far eliminated in many cases that this ceases to have a controlling influence upon the design and proportions may be quite freely selected with a view to economizing material. In other cases, however, especially for high-speed machines, commutation presents the principal problem for the designer and the whole machine has to be built up around this limitation. The general guides suggested above take account of these restrictions and for machines which present no peculiar difficulties they have been found empirically to lead to proportions which will require few alterations when it comes to working out the final details.

After the dimensions of the armature have been settled, no particular engineering difficulties are involved in designing a suitable field to go with it, and it is now possible to proceed confidently to the completion of the design. The no-load magnetization curve should be constructed and this should be employed to determine the effect of armature reaction. Then the temperature rise of the armature should be estimated, and if this is satisfactory, the proportions for the field coils should be determined. This completes the layout, but the designer's task is not yet finished, for he must assure himself that he has utilized his material to the best advantage. This can only be accomplished by preparing several alternative designs which readily suggest themselves after one layout has been completed. Cost estimates should then be prepared for each design, which should serve as a basis for the final choice.

Considering now very briefly some of the lines of service where this type of direct-current interpole motor may be employed, we find that it has demonstrated its superiority over other forms for cranes, hoists and all forms of traction where the cost of distribution is not a controlling factor. The adjustable speed feature of the motor makes it peculiarly adaptable to the operation of large machine tools, printing presses, paper-making machines, to many of the auxiliary drives in steam-generating stations and to ship propulsion where a wide range in cruising speed is desired. A four-to-one adjustment in speed may readily be provided, and this may be obtained either entirely by shunt field regulation, or in combination with two voltages on the three-wire

system or entirely by voltage control through the use of a motor generator set. In the last case the duty may be more severe upon the generator of the motor generator set than upon the variable speed motors, for heavy currents have to be commutated at low voltages and consequently very weak fields. We are inclined to think of the direct-current motor with its commutator as being particularly vulnerable compared with the rugged squirrel-cage type of induction motor, and yet we find the direct-current motor selected for the most exacting requirements in the operation of steel mills where the conditions of service are probably more severe than in any other line of work. There they are employed not only for the heavy duty of cranes, hoists, transfer tables and for handling the molten metal where it is absolutely essential to guard against loss of motive power, but also for driving the main rolling mills. Alternating-current motors may be used where the drive is in one direction, but when the motor is reversed with every passage of the metal through the rolls, the interpole compensated field type is employed. High speed of reversal is essential and in some of the recent installations the motors are brought from full speed forward to reverse in three seconds. The motors for this service range in capacity from about 3000 to 8000 horsepower at maximum speeds from 50 to 120 r.p.m. and represent the largest direct-current motors so far constructed.

With the tremendous development that has taken place in alternating-current practice within recent years, there is a tendency to think of direct-current apparatus as being somewhat out of date. I trust that this review of the subject may serve to remind us that in many extensive lines of work the direct-current interpole motor still reigns supreme.

Stability of Vitamin C in Dried Orange Juice.—GERTRUDE J. HUMPHREY (*Jour. Biol. Chem.*, 1926, **69**, 511–512) has tested biologically a preparation which had been made by addition of sugar to orange juice to produce 25 per cent. of total solids, followed by drying and storage in a partial vacuum. The preparation had been kept for over five years. Young guinea-pigs were fed a diet which produces scurvy, and received daily doses of the dried orange juice for a period of thirty-two days. They failed to develop scurvy. Therefore, the anti-scorbutic vitamin, or water-soluble C, in the dried orange juice had retained its activity at the end of five years' storage.

J. S. H.

THE CONTRAST OF PHOTOGRAPHIC PRINTING PAPER.*†

BY

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SECTION B. STATISTICAL.

In this section is given a detailed account of experimental work done to determine the characteristics (γ_n and DS_n) of the negatives which will give the best possible tone reproduction of a selected test-object upon various developing-out papers differing widely in contrast value. If the negative material and test-object are properly chosen, the entire brightness scale of the object can be rendered on the straight line portion of the negative material; hence different extents of development will yield negatives which differ only in gamma and density scale. Therefore these negatives, from the standpoint of tone reproduction and contrast, can be completely specified by these values. If the same object is used for all negatives, the brightness scale (BS_0) is constant and hence the exposure scale for the different negatives of the group is constant. The density scale of the negative is, therefore, directly proportional to gamma and hence the *relative* quality of the different negatives can be completely specified by a single value, either gamma or density scale. The negative which gives the best print quality with any particular paper will be referred to as the *optimal negative* and a correctly exposed print produced therefrom will be the *optimal print*. The value of density scale for the optimal negative being known, it can be laid off on the characteristic curve of the positive material, and in this way the portion available for the reproduction of the particular object rendered by the negative, can be determined. The contrast for the positive material can then be computed, and moreover, the data obtained by this statistical study can be utilized for other purposes, such as the determination of the tone reproduction obtainable with various combinations of negative and positive characterstics.

* Communicated by Dr. C. E. K. Mees, Director of Laboratory, and published as Communication No. 264 from the Research Laboratory of the Eastman Kodak Company.

† Continued from p. 204 of the August issue.

The measurement of the γ_n and DS_n is easily accomplished by the usual sensitometric methods, while the negative best suited to any particular paper can be determined by making several prints on the positive material from a series of negatives varying slightly in contrast, and subsequently choosing the print which shows the best quality. Judgment of print quality involves, to a certain extent, personal taste and may vary somewhat with the experience and training of the observer. In order to secure reliable data it is necessary, therefore, to obtain the judgment of a large number of individuals, then, by averaging results, arrive at a mean value from which the characteristics of the optimal negative may be determined. The various steps necessary in this process may be briefly stated as follows:

(1) The making of a series of negatives, of the same object, varying only in the extent to which they are developed.

(2) The determination of the gradient (γ_n) and density scale (DS_n) for these negatives.

(3) The making of a series of prints from these negatives on the printing papers of which it is desired to determine the contrast.

(4) The examination of these prints and the determination of the negative producing the print of best photographic quality for each of the printing papers under the examination.

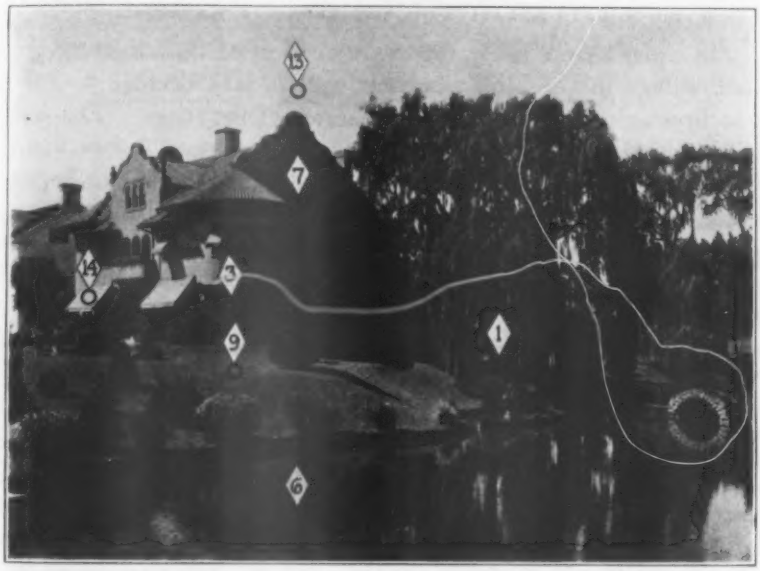
I. DATA RELATIVE TO THE OBJECT.

The portion of the characteristic curve of a positive material available for use will depend, to a certain extent, upon the brightness scale of the object, BS_0, chosen for making the required series of negatives. Careful consideration was, therefore, given to the choice of a scene and a type was adopted which may be referred to as an *average* landscape.

In Fig. 5 is shown a reproduction of a print made from one of the negatives. For convenience in referring to this picture, the name "Willow Pond" has been adopted. It will be noted that the scene includes a rather wide variety of component parts such as trees, water, architectural detail, grass, shrubbery, sky, etc. In order that the information regarding the object be as complete as possible, brightness measurements of various conspicuous elements were made by means of a portable photometer. The areas measured are included in the black circles and are designated by the adjacent number. The data thus obtained

are given in Table II. It will be noted that the lowest brightness (64 ml.) was found on the trunk of a willow tree at the position marked No. 1, while the highest brightness (2500 ml.) was found

FIG. 5.



The "Willow Pond" normal landscape, showing areas of measured brightness.

at point No. 14, the top of the awning in bright sunlight. The ratio of the highest to the lowest brightness is 39, which is a

TABLE II.

Values of Brightness, Measured Photometrically, at Various Points in the "Willow Pond" Normal Landscape.

Spot No.	Location.	B_0 (r).	Log B_0 (r).
1	Trunk of willow tree, in shadow	64	1.81
3	Shadow under porch	85	1.93
6	Shadow on water, left of centre	200	2.30
7	Gable in shadow	300	2.48
11	Lawn, to right of centre	1000	3.00
13	Sky (blue) above gable	2200	2.34
14	Awning in sunlight	2500	3.40
..	Contrast	39	1.59

specification of the brightness contrast. The logarithm of this value is 1.59, which represents a numerical specification of the *extent* factor of brilliance contrast. The negatives were made

shortly after noon on a fairly clear day. The sky, while not overcast, was of a light blue color resulting from the presence of a certain amount of water vapor in the air but not collected into a visible cloudiness.

II. DATA RELATIVE TO THE NEGATIVE MATERIAL.

In order that a fairly true reproduction of the visual scale of tone values in the object be obtained, it was decided to use a panchromatic plate in making the series of negatives. The scene being photographed contained elements of various colors which, if an ordinary blue-sensitive plate were used, would not be rendered in their true visual tonal relation. While the panchromatic plate used without a filter does not give absolutely correct orthochromatic rendering of colored objects, the reproduction is much more satisfactory and in better agreement with the visual impressions than is obtained with ordinary blue-sensitive materials. Wratten Fast Panchromatic plates, which on test gave an H. and D. speed of 250, were therefore chosen for making the negatives. From the known speed of the negative material, the f number of the lens used, and the measured brightness of the deepest shadow (spot No. 1, Fig. 5), it was possible to compute the time of exposure required to render the deepest shadow by a negative density at the lower limit of the straight line portion of the characteristic curve.

Twelve exposures were made, one after the other, as rapidly as the plate holders could be changed so as to avoid as completely as possible any change of the lighting on the object. Before attempting the development of these negatives, it was necessary to determine the time of development required to give the desired series of gamma values. Sensitometric strips cut from plates from the same coating as those used in the camera were exposed in the sensitometer and developed under standard conditions. The developer used was the standard pyro soda developer used in this laboratory for testing purposes, and the times of development were so chosen as to give practically the entire available range of gamma values. In Table III, section 1, the data relative to this preliminary work are given. In the column designated as T_d are the times in minutes for which various of these sensitometric strips were developed and in the column designated as $\gamma_x(v)$ are

values of γ obtained for the times of development indicated. These values are shown graphically in Fig. 6, which is the time-

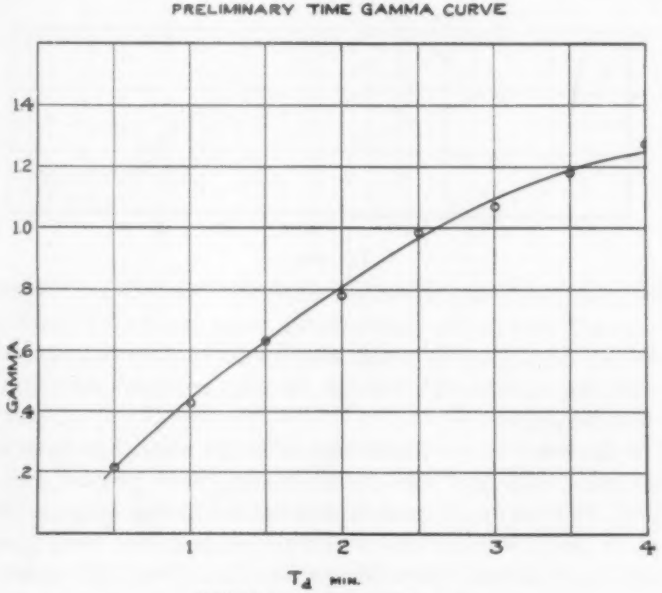
TABLE III.

The Relation between Gamma, Measured Visually, and the Time of Development for the Negative Material Used in Making the Group of Test Negatives.

Section 1. Preliminary.			Section 2. Final.			
Strip.	T_d (min.).	γ_x (v).	Strip.	Neg.	T (min.).	γ_x (v).
1	.50	.28	1	1	.83	.39
2	1.0	.43	2	2	1.17	.51
3	1.5	.63	3	3	1.42	.60
4	2.0	.78	4	4	1.67	.68
5	2.5	.98	5	5	2.00	.83
6	3.0	1.06	6	6	2.40	.93
7	3.5	1.17	7	7	2.75	1.05
8	4.0	1.26	8	8	3.00	1.15
9	4.5	1.32	9	9	3.75	1.29

gamma function for this particular negative material when developed in the specified developer. From the smooth curve drawn

FIG. 6.

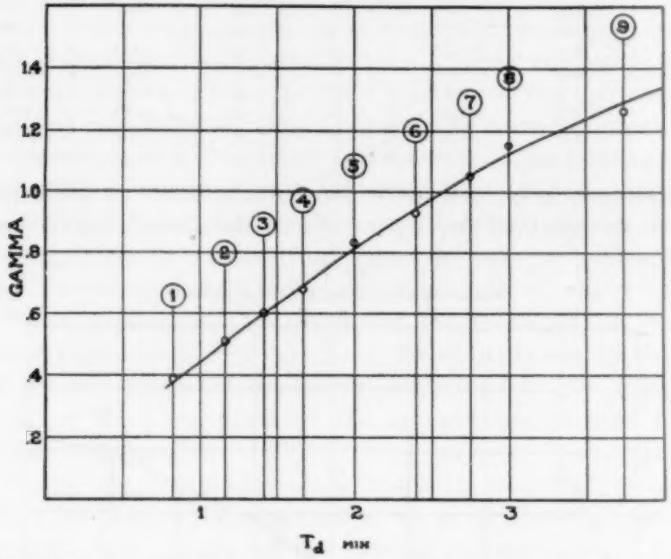


Preliminary time-gamma curve.

through the plotted points, it is now possible to determine the time of development required to give any desired gamma.

From preliminary information as to the values of γ_n required to give satisfactory results with the various printing papers, it was decided that the series of negatives, in which the gamma value increased by steps of .1 and extending over a range from .4 to 1.4, would be adequate for all grades of developing-out papers. The times of development required, as indicated by the curve in Fig. 6, were determined and the negatives developed accordingly. Two strips, of the same negative material, which

FIG. 7.



Final time-gamma curve showing the gamma values of the series of test negatives.

had been exposed in the sensitometer, were attached to each negative during development so that they received development, fixing, and washing treatment identical to that received by the negatives themselves.

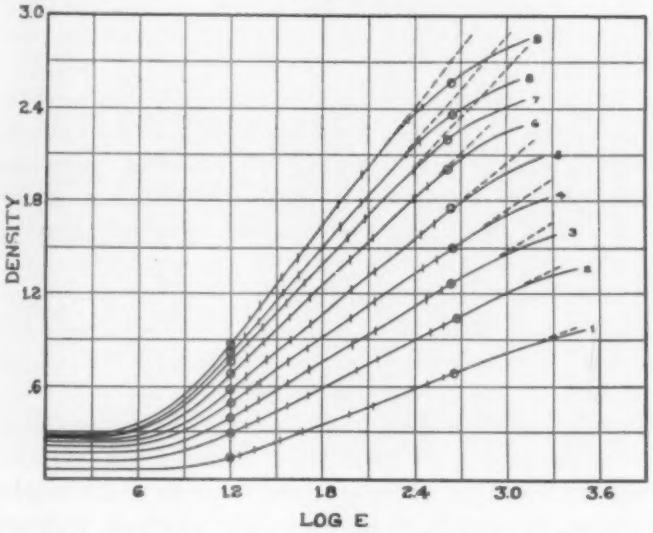
The densities of the sensitometric strips were then determined in the usual way and the characteristic curve plotted for each negative. The values of gamma determined in this way are shown in section 2 of Table III. From these data, the final gamma-time of development curve shown in Fig. 7 was plotted. The smooth curve was drawn through the plotted points and from this curve all finally accepted values of gamma for the various negatives were read. It will be noted that some of the plotted

points do not fall upon the smooth curve. In such cases it is considered that the most probable value of the gamma of a negative is obtained by reading from the smooth curve rather than taking the actual measured gamma value from the strips developed with that negative.

III. DATA RELATIVE TO THE NEGATIVES.

These most probable values as read from the smooth curve in Fig. 7 are given in Table VI. It will be noted that the agreement

FIG. 8.



Characteristic curves of the negative material on which the test negatives were made. These curves show, as indicated by the attached number, the extent to which each of the test negatives was developed.

between the curves in Figs. 6 and 7 is very good, and although the final curve runs somewhat higher for the longer time of development, the agreement is well within the limits of variation to be expected in photographic processes. It will be noted that only data relative to negatives from No. 1 to No. 9 are given. When the prints were made, it was found that no paper sufficiently soft to require a negative of greater contrast than that of No. 9 was obtainable. It is, therefore, thought superfluous to give the data on negatives of greater contrast. In Fig. 8 are plotted the characteristic curves for the nine negatives used. The density values plotted there are inclusive of fog, which accounts for the

tendency of the curves of the longer development times to rise and shift to the left. It will be noted that the straight line portion of these curves extended do not intersect at a point. This is accounted for by the fact that the density values plotted include the fog. It will be found that if the fog value, as indicated by the height of the horizontal portion of the curve at the extreme left hand of the figure, be subtracted from the density values, that the straight line portion of these various curves will intersect in a fairly well-defined point, lying slightly below the log E axis.

A set of negatives was thus obtained for which the values of gamma are known. From the standpoint of the statistical method no further information, other than the value of the density scale (which can be obtained from a measurement of maximum and minimum density) relative to the characteristic of these negatives, is necessary; but since it is desired, if possible, to correlate the results obtained by the statistical method with the sensitometric characteristics of the negative and positive materials, it was considered advisable to study the negatives themselves in somewhat greater detail. In order to make the computations as to the quality of tone reproduction obtained, it is necessary to fully analyze the distribution of density throughout the negatives. Density measurements were therefore made on the negatives themselves, using a densitometer [28] specially adapted to the measurement of the density of small areas scattered over the surface of a large negative. In addition to the areas on which brightness measurements were made, as shown in Fig. 5, certain other typical areas of interest were chosen for measurement. Since the variation in density from point to point on the negative may in some cases be very rapid, it is necessary, if consistent results are to be obtained, that some method of precisely locating corresponding points on the various negatives be desired. This was accomplished in the following manner.

On a print from one of the negatives the points chosen for density measurement were marked. This print was then placed on top of a pile of 8 × 10 sheets of black paper and held firmly in place. Using a small punch, a hole approximately 3 mm. in diameter was punched at each of the points designated on the print. In this way a group of opaque masks was obtained, in each of which was a number of holes so distributed that when

placed in register over the various negatives, identical details of the picture were automatically isolated by each of the openings in the opaque mask. For the purpose of register, two holes, marked *R* in Fig. 9, were punched in each of the masks in such a way that when the same conspicuous negative details were

FIG. 9.

The "Willow Pond" test-object showing points at which density measurements were made on the negatives.

brought into the centre of the two openings, precise register of the opaque mask with the negative was assured. Each mask, when in proper register with its negative, was fastened in position in contact with the emulsion side of the negative, and the negative carrying its mask placed in the densitometer for measurement. Density measurements on each of the nine negatives were made at each of the numbered spots shown in Fig. 9.

The density values thus obtained are shown in Table IV. In the extreme left-hand column, the number of the point to which the density measurement applies is indicated. The various columns of density values apply to the negatives as indicated by the number at the top of the columns. When these measurements were examined, it was found that points 1 and 2 gave

density values which were not, on the average, appreciably different. It must, therefore, be assumed that points 1 and 2 represent areas so nearly equal in photographic brightness that they are not distinguishable as different by this process. It was, therefore, decided to average the values obtained on points 1 and 2 and to consider this mean as representing the density value of object

TABLE IV.

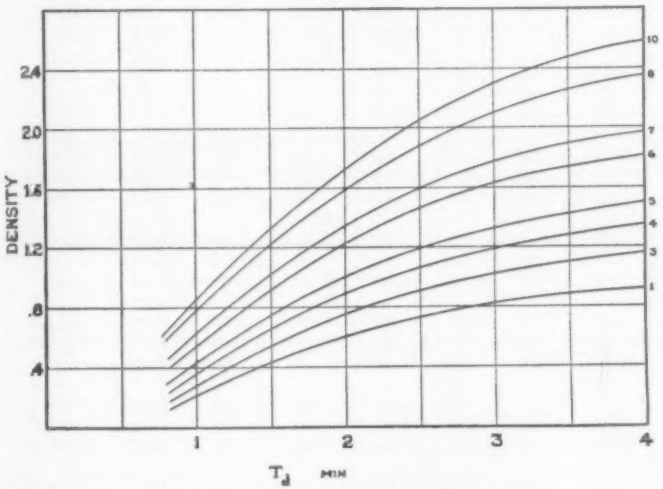
The Densities, as Measured Visually at Corresponding Points on the Group of Negatives. The Numbers in the First Column of the Table Refer to the Points as Indicated by the Numbers in Fig. 9.

Point No.	Negative No.								
	1	2	3	4	5	6	7	8	9
1	.11	.32	.41	.52	.58	.73	.76	.84	.90
2	.13	.30	.40	.50	.56	.71	.77	.86	.88
Mean	.12	.31	.40	.51	.57	.72	.76	.85	.89
3	.15	.36	.46	.55	.68	.79	.90	.95	1.00
4	.16	.38	.52	.66	.77	.88	1.03	1.08	1.12
5	.24	.47	.64	.77	.89	1.04	1.12	1.24	1.28
6	.26	.53	.70	.80	1.00	1.16	1.22	1.29	1.50
7	.35	.69	.87	1.02	1.24	1.41	1.51	1.67	1.78
8	.36	.67	.85	1.00	1.16	1.35	1.50	1.63	1.74
9	.36	.69	.90	1.03	1.21	1.37	1.56	1.71	1.80
10	.40	.77	.91	1.05	1.23	1.38	1.65	1.71	1.78
Mean	.37	.70	.88	1.02	1.21	1.38	1.56	1.68	1.78
11	.44	.78	.94	1.13	1.30	1.50	1.67	1.82	2.00
12	.60	.96	1.18	1.36	1.52	1.77	2.08	2.12	2.31
13	.63	1.00	1.22	1.40	1.63	1.85	2.10	2.20	2.38
14	.65	1.03	1.27	1.50	1.65	1.90	2.20	2.30	2.47
15	.70	1.06	1.32	1.48	1.70	2.00	2.15	2.32	2.57
Mean	.68	1.05	1.28	1.49	1.68	1.95	2.18	2.31	2.54

brightness No. 1. Points 3, 4, 5, and 6 are definitely different in density and therefore represent definitely different photographic brightnesses. Points 7, 8, 9, and 10 are so nearly alike in photographic brightness that the density values do not serve to definitely distinguish one as more or less bright than the others. The density measurements for Nos. 7, 8, 9, and 10 were, therefore, averaged and the average value taken as indicative of a single object brightness. Points 11, 12, and 13 also definitely differ in brightness as indicated by the density measurements. Points 14 and 15 are so nearly alike as to be indistinguishable and these density values were averaged. While density measure-

ments were made on fifteen different points in the negative, the results yield but ten distinctly different object brightnesses. It will be observed that there are certain fluctuations and apparent inconsistencies in the values given in Table IV. In order to reduce these to a minimum a graphic method of smoothing was adopted. From the density values in Table IV, the curves shown in Fig. 10 were plotted. The actual points are not shown in this figure, but, needless to say, all points do not fall precisely upon

FIG. 10.



Curve showing the growth of density with increasing times of development for each of the areas of measured density.

the curves as drawn. The order of scattering is very similar to that shown in Fig. 7. One curve was plotted for each of the brightness values. The numbers along the right-hand side of Fig. 10 indicate the brightness value to which each of the curves apply. Curves for object brightness Nos. 2 and 9 are omitted since they fall so close to curves 1 and 10 as to cause confusion in plotting.

Now in order to arrive at the most probable density values for the various points measured, the values were read from the smooth curves shown in Fig. 10. In Table V these values are entered in the horizontal lines designated at the extreme left by the word "curve." Immediately above these are the actually observed density value and in the line designated as $\triangle D$ are shown

the departures between the values read from the smooth curves and those actually observed. It will be noted that in no case are the departures of great magnitude and it is thought, considering the

TABLE V.

Data Showing the Density Differences between the Actually Observed Values and Those Read from the Smoothed Curves.

	Negative No.								
	1	2	3	4	5	6	7	8	9
Obs.	.12	.31	.40	.51	.57	.72	.76	.85	.89
Curve	.12	.29	.40	.50	.58	.69	.77	.81	.87
ΔD	.00	−.03	.00	−.01	+.01	−.03	−.01	−.04	−.02
Obs.	.15	.36	.46	.55	.68	.79	.90	.95	1.00
Curve	.15	.34	.46	.57	.67	.78	.88	.92	1.02
ΔD	.00	−.02	.00	+.01	−.01	−.01	−.02	−.03	+.02
Obs.	.16	.38	.52	.66	.77	.88	1.03	1.08	1.12
Curve	.18	.38	.51	.63	.77	.88	.98	1.03	1.13
ΔD	−.02	.00	−.01	−.03	.00	.00	−.05	−.05	+.01
Obs.	.24	.47	.64	.77	.89	1.04	1.12	1.24	1.28
Curve	.24	.47	.62	.75	.90	1.04	1.14	1.21	1.30
ΔD	.00	.00	−.02	−.02	+.01	.00	+.02	−.03	+.02
Obs.	.26	.53	.70	.80	1.00	1.16	1.22	1.29	1.50
Curve	.30	.54	.70	.84	1.00	1.16	1.26	1.32	1.44
ΔD	+.04	+.01	.00	+.04	.00	.00	+.04	+.03	−.06
Obs.	.37	.70	.88	1.02	1.21	1.38	1.56	1.68	1.78
Curve	.41	.70	.87	1.03	1.22	1.42	1.56	1.63	1.78
ΔD	+.04	.00	−.01	+.01	+.01	+.04	.00	−.05	.00
Obs.	.44	.78	.94	1.13	1.30	1.50	1.67	1.82	2.00
Curve	.47	.77	.96	1.14	1.34	1.55	1.68	1.78	1.94
ΔD	+.03	−.01	+.02	+.01	+.04	+.05	+.01	−.04	−.06
Obs.	.60	.96	1.18	1.36	1.52	1.77	2.08	2.12	2.31
Curve	.61	.95	1.16	1.36	1.58	1.81	2.00	2.10	2.32
ΔD	+.01	−.01	−.02	.00	+.06	+.04	−.08	−.02	+.01
Obs.	.63	1.00	1.22	1.40	1.63	1.85	2.10	2.20	2.38
Curve	.65	.99	1.22	1.42	1.65	1.89	2.08	2.18	2.41
ΔD	+.02	−.01	.00	+.02	+.02	+.04	−.02	−.02	+.03
Obs.	.68	1.05	1.28	1.49	1.68	1.95	2.18	2.31	2.54
Curve	.67	1.04	1.26	1.50	1.73	1.99	2.18	2.34	2.58
ΔD	−.01	−.01	−.02	−.01	+.05	+.04	.00	+.03	+.04

inherent difficulty of this type of work and the unavoidable irregularities of the materials themselves, that the precision obtained is highly satisfactory. From the curves in Fig. 10 or from the *curve* values in Table V, it is now possible to determine with

considerable certainty the maximum and minimum density for each of the nine negatives. These values are shown in Table VI

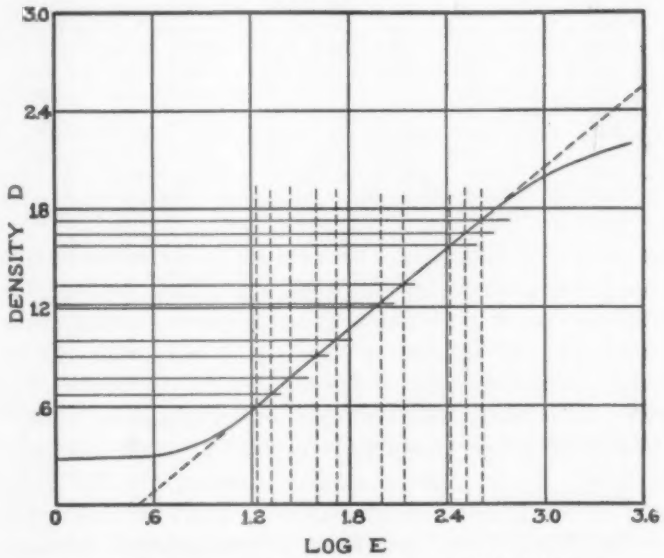
TABLE VI.

The Values of Various Factors Relating to the Group of Test Negatives.

Neg.	T_d.	$\gamma_n(v)$.	$D\text{min.}(v)$.	$D\text{max.}(v)$.	$DS_n(v)$.	$BS_0(p)$.	$DS_n(p)$.	$\gamma_n(p)$.	$\phi_n(p)$.
1	.83	.38	.12	.67	.55	1.46	.67	.46	.46
2	1.17	.51	.29	1.04	.75	1.48	.92	.62	.62
3	1.42	.60	.40	1.26	.86	1.44	1.05	.73	.73
4	1.67	.69	.50	1.50	1.00	1.45	1.22	.84	.84
5	2.00	.82	.58	1.73	1.15	1.43	1.41	1.00	.99
6	2.40	.96	.69	1.99	1.30	1.41	1.59	1.17	1.12
7	2.75	1.05	.77	2.18	1.41	1.41	1.72	1.28	1.22
8	3.00	1.14	.81	2.34	1.53	1.42	1.89	1.39	1.32
9	3.75	1.32	.87	2.58	1.72	1.44	2.10	1.61	1.49
Mean						1.44			

in the columns designated as D max.(v) and D min.(v). If now the minimum density be subtracted from maximum density, the

FIG. 11.



Illustrating the method of finding relative photographic brightness.

values of the density scale of the negative are obtained. These values are shown in the column designated as $DS_n(v)$.

Knowing now the density by which the various areas designated by the numbered spots in Fig. 9 are rendered in any given

negative, and assuming that the characteristic curves shown in Fig. 8 represent correctly the gradient (γ_n) to which these negatives are developed, it is possible to determine the relative photographic brightnesses of the corresponding points in the object. The method of obtaining these values is illustrated in Fig. 11. The characteristic curve there plotted is a duplicate of curve No. 5 in Fig. 8 (for negative No. 5).

Along the density (D) axis are laid off the values shown in column 5 in Table V (the values used being those read from the

TABLE VII.

The Data Used in Computing the Relative Photographic Brightness of the Various Points Indicated in Fig. 9.

Brightness Number (B_o).

Neg.	1	2	3	4	5	6	7	8	9	10
1	1.18	1.26	1.36	1.52	1.67	1.98	2.13	2.48	2.59	2.66
2	1.20	1.30	1.38	1.56	1.70	2.02	2.16	2.50	2.59	2.68
3	1.20	.30	.39	.57	.71	1.99	.14	.48	.57	.64
4	1.21	.31	.39	.57	.70	1.98	.13	.45	.54	.65
5	1.21	.31	.43	.59	.72	1.99	.14	.43	.52	.63
6	1.20	.31	.41	.58	.71	1.98	.12	.39	.48	.61
7	1.20	.31	.41	.56	.68	.96	.08	.39	.50	.61
8	1.19	.29	.39	.55	.65	.92	.05	.34	.42	.64
9	1.22	.32	.40	.54	.64	.92	.03	.36	.45	.64
Mean	1.20	1.30	1.40	1.56	1.69	1.97	2.11	2.42	2.52	2.64
$\triangle$ Log E	.01	.012	.015	.015	.023	.025	.037	.049	.049	.016
$\triangle B(\%)$	2.3	3.4	3.5	3.6	3.4	5.9	8.7	11.9	12	3.8
$B_o(p)$	1.58	20	25.1	36.3	49	93.3	129	263	331	437

smooth curves of Fig. 10). From these points thus established on the density axis, horizontal lines are drawn intersecting the characteristic curve and from these points of intersection the perpendiculars are dropped to the log E axis. At the points where these perpendiculars cut the log E axis, the values of log E are read. The values thus obtained are tabulated in Table VII, in the horizontal line designated by No. 5 at the extreme left of the table. In an exactly similar manner, the log E values for each of the points indicated in Fig. 9 are determined from each of the nine different negatives. If the process were entirely free from error, the log E value for each brightness number as determined on the different negatives should be the same. It will be noted by reference to Table VII, that the variation in the vertical columns, representing the log E value applying to each of the brightness numbers, is not great. In the horizontal line at

the bottom of the table designated by "mean," are the average log E values for each of the specified brightness numbers. Immediately below these values are the mean deviations from the mean expressed in terms of log E and in the next lower line these mean deviations are expressed as the percentage of the brightness value itself. Since the exposure time in making the negatives was constant for all negatives and for the entire area of each negative, the object brightness must be directly proportional to the exposure values as determined in this manner. In the bottom line of Table

TABLE VIII.

The Relation between Values of Visual and Photographic Brightness for Various Areas in the Test-object.

Spot No.	Location.	Brightness.		
		No.	$B(p)$.	$B_0(v)$.
1	Tree trunk, in shadow	1	90	65
2	Tree trunk, in shadow	1	90	..
3	Shadow under porch	2	114	85
4	Shadow in front doorway	3	143	..
5	Wall in shadow	4	208	..
6	Shadow on water, left of centre	5	280	200
7	Gable in shadow	6	535	300
8	Wall of circular tower	6	535	..
9	Lawn, centre	6	535	..
10	Lawn, left	6	535	..
11	Lawn, right	7	740	1000
12	Wall in sun, above awning	8	1500	..
13	Sky above gable	9	1900	2200
14	Awning in sun	10	2500	2500
15	Sky through trees	10	2500	..
	Brightness contrast in object		28	38
	Log of maximum brightness		3.40	3.40
	Log of minimum brightness		1.95	1.81
	Brightness scale of object (BS_0)		1.45	1.79

VII are given the relative brightness values $[B_0(p)]$ determined in this way. Since the log E scale used in plotting the characteristic curve shown in Fig. 8 is an arbitrary one, these values are only relative.

We are now in position to compare the brightness of various parts of the object measured visually with the brightness of these same points determined photographically. In Table VIII this comparison is made. In the column at the extreme right of the table designated as $B_0(v)$ the values of brightness for those areas on which measurements were made, as determined visually, are given. In the column designated as $B_0(p)$ are the relative

brightness values as determined photographically. For the purpose of comparison, it has been assumed that the photographic brightness for point 14 is the same measured photographically as measured visually. The other values in this column are therefore obtained by taking the values in the bottom row of Table VII and increasing this proportionately on the assumption that brightness No. 14 is equal to 2500. It will be noted that the deepest shadow has a considerably higher brightness value when determined photographically than when determined visually. Furthermore, the values in the half-tone do not compare especially well with the values determined visually. It is well known that any photographic lens, having a number of free glass-air surfaces, produces a certain amount of flare which tends to cause a lowering of the contrast in the illumination incident upon the photographic plate below the actual objective contrast of the object photographed. The presence of color in the object is also responsible to a certain extent for the distortion between photographic and visual brightness values. The brightness contrast in the object as determined visually is 38, while as determined photographically it is 28. The extent of brilliance contrast determined visually is 1.79 and determined photographically is 1.45.

From the relative log E values tabulated in Table VII, it is now possible to find the brightness scale of the object as determined photographically by each negative. For instance, in the case of negative No. 1 the relative log E value corresponding to brightness No. 10 (Spot 14, Fig. 10) is 2.64, while the minimum log E value corresponding to brightness No. 1 (Spot 1, Fig. 10) is 1.18. The difference between these two values is 1.46, which, therefore, is the brightness scale of the object as measured photographically. The values as determined from measurements made on the other negatives of the set are shown in the column (Table VI) designated as $BS_0(p)$. It will be noted that the mean of the nine values thus obtained is 1.44 and that the deviation between the various individual values is small. This value is of considerable importance in our later attempts to correlate the statistical values with the sensitometric characteristics of the papers.

Color Coefficient.—As was stated previously, the development of this group of negatives was carried out in a pyro soda developer. In deciding upon the use of this developer, we were

influenced to a great extent by the general consensus of opinion among professional photographers to the effect that the pyro developers yield negatives of a quality superior to those obtained by the use of any other developing agent. While this has not been definitely substantiated by sensitometric evidence, it was decided to use the pyro developer in this work in spite of the fact that the yellow stain present in negatives developed by this reducing agent, complicates to some extent the determination of the effective photographic contrast of the negative.

Since photographic printing papers are sensitive only to blue, violet, and ultra-violet radiation, a yellow deposit such as is produced by development in pyro solution has a greater photographic density than is indicated by visual measurement. All density measurements made on the sensitometric strips and the negatives themselves were made by a direct visual comparison and hence are not true measures of the effective density of the various deposits from the standpoint of the positive materials on which the prints are subsequently to be made. The factor by which the visual density value must be multiplied in order to convert it to the photographic density, is termed the *color coefficient* which is designated by the symbol χ. The value of χ depends upon the *spectral selectivity* of the deposit under consideration and the *spectral sensitivity function* of the material in terms of which it is desired to evaluate the density. The method of determining the value of χ has been treated at length in a previous paper.[29]

Using the sensitometric strips which were developed with the group of negatives, and various positive materials on which prints were to be made, the value of color coefficient was determined. While it is well known that different kinds of developing-out papers differ to a certain extent in spectral sensitivity, the values of color coefficient obtained on the various types did not differ sufficiently to necessitate the use of a different value of color coefficient for each kind of printing paper. The values obtained were, therefore, averaged, giving a mean value of 1.20. From the density measurements made on the negatives themselves and on the prints, it is possible, with the aid of the sensitometric curves of the positive materials, to compute directly the color coefficients of the negatives. This was done for the optimal print from each of the papers used and the values of χ thus obtained were averaged. This gave a value of 1.22 with a mean

deviation from the mean of 3.2 per cent. Since this value is based on a larger number of determinations and is derived directly from the negative, it was used in preference to that obtained from the sensitometric strips. It is necessary, therefore, to multiply all of the density values measured visually by 1.22 in order to obtain the equivalent photographic density. Since the entire scale of object brightness and negative densities lies upon the straight line portion of the negative characteristic, it is only necessary to multiply the values of gamma obtained from the visual density measurements by χ (1.22) in order to obtain the effective photographic gamma $[\gamma_n(p)]$. In the last three columns of Table VI are tabulated the values of $DS_n(p)$, $\gamma_n(p)$, and $\phi_n(p)$, these values all being obtained by use of the color coefficient ($\chi = 1.22$). The letter p placed in parenthesis after a symbol such as D (density), γ (gamma), DS (density scale), etc., indicates that the value is given in photographic terms; while the use of v in a similar manner means that the quantity is expressed in visual terms: Thus

$D_n(p)$ = photographic density of negative.
$D_n(v)$ = visual density of negative.

From an inspection of Fig. 8 it will be seen that as the time of development was increased, the shape of the characteristic curve changed in such a way that some of the higher object brightnesses were not rendered on the straight line portion of the curve. The departure from the straight line condition, however, is not sufficiently great to interfere seriously with the usage of gamma as indicative of negative gradient. It is evident that if all of the object brightnesses had been rendered on the straight line portion of the characteristic curve that ϕ_n should be equal in all cases to γ_n. A comparison of the last two columns in Table VI will show the extent of departure from this condition. Up to and including negative No. 8, the discrepancy between these values is less than 5 per cent. It is considered that this deviation is too small to invalidate our assumption that the gradient of the negatives is adequately expressed by the value of gamma.

The difference between photographic and visual values of density should be constantly kept in mind, and if the results of density measurement made on negatives are to be applied to the

computation of results obtained by printing these densities on positive materials. Great care should be exercised in all cases to be certain that the density values are correct from the photographic standpoint. From this point on throughout the paper, all values of density, gamma, scale, latitude, etc., as applying to the negatives and negative materials, will be expressed in photographic terms unless specifically stated to the contrary.

We have now carried the work to the point where a group of negatives of precisely known characteristics are available for printing on the papers for which *contrast* is to be determined. The values in Table VI represent effectively a summary of the data relative to these negatives.

IV. DATA RELATIVE TO THE POSITIVES (PRINTS).

Characteristics of the Papers Used.—In order to make the results of contrast determination as conclusive as possible, it is essential to apply the method to a group of printing papers representing as great a range in characteristics as is possible to obtain. From the entire group of developing-out papers manufactured by this company, thirty-seven representative papers were chosen.

In Table IX an attempt is made to state, in a general way, the characteristics of these materials. The columns designated as *surface, thickness,* and *color* contain approximate verbal specifications of these characteristics. In the last column, the contrast is designated by the verbal term usually applied as descriptive of this characteristic. It should be pointed out that this work was started some time ago. The papers used, therefore, represent the quality of the material as manufactured at that time. Since that time there has been considerable change in the quality of certain of the papers. It should be realized, therefore, that the characteristics, as determined herein, may not necessarily apply to these papers as manufactured at the present time. This does not in any way invalidate the conclusions reached since all of the work, both statistical and sensitometric, was carried out upon these particular materials. This paper does not purport to give quantitative values of contrast for any specific brands of papers, the aim is only to develop a method for the specification of contrast and to point out the relation existing between negative and positive characteristics under certain definitely specified conditions. The

TABLE IX.

Qualitative Specifications Relative to Developing-out Papers Used in This Work. General Characteristics.

No.	Trade Name.	Surface.	Thickness.	Color.	Contrast.
1	Azo A	Matte	DW	White	Soft
2	Azo A	Matte	DW	White	Hard
3	Azo A	Matte	DW	White	Hard X
4	Azo E	Semi-matte	DW	White	Soft
5	Azo E	Semi-matte	DW	White	Hard
6	Azo E	Semi-matte	DW	White	Hard medium
7	Azo E	Semi-matte	DW	White	Hard X
8	Azo F	Glossy	SW	White	Soft
9	Azo F	Glossy	SW	White	Hard
10	Azo F	Glossy	SW	White	Hard medium
11	Azo F	Glossy	SW	White	Hard X
12	Azo K	Glossy	SW	White	Hard medium
13	Azo K	Glossy	SW	White	Hard X
14	Velox	Carbon	SW	White	Special
15	Velox	Carbon	SW	White	Regular
16	Velox	Velvet	DW	White	Special
17	Velox	Velvet	DW	White	Regular
18	Velox	Glossy	DW	White	Special
19	Velox	Glossy	DW	White	Regular
20	Velox	Velvet	DW	White	Special portrait
21	Velox	Velvet	DW	White	Contrast
22	Artura Iris A	Semi-matte	SW	White	Soft
23	Artura Iris E	Smooth matte	DW	Cream	Soft
24	Artura Iris D	Rough matte	DW	White	Soft
25	Artura Aegis No. 1	Smooth matte	DW	White	Soft
26	Artura Chloride	Smooth	DW	White	Medium
27	Artura NC	Satin	SW	White	Soft
28	Artura NC	Satin	SW	White	Medium
29	Artura NC	Satin	SW	White	Hard
30	Artura Carbon Black	Matte	SW	White	Medium
31	Artura Carbon Black	Studio special	SW	White	Medium
32	Artura Carbon Black	Glossy	SW	White	Medium
33	Bromide BB	Smooth	DW	White	Soft
34	Bromide EP	Velvet	SW	White	Soft
35	Bromide EP	Rough	DW	Buff	Soft
36	Bromide EP	Enameled	SW	White	Soft
37	Bromide EP	Matte enamel	SW	White	Soft

numbers in the first column of Table IX will, from this point on, be used as a means of identification for the various papers.

Making of Prints.—When the work of making the prints

TABLE X.

Test Negatives Used in Making Prints on the Various Developing-out Papers.

Paper.	Negatives Used, No. and $\gamma(p)$.								
	1 $\gamma=.46$	2 $\gamma=.62$	3 $\gamma=.73$	4 $\gamma=.84$	5 $\gamma=1.00$	6 $\gamma=1.17$	7 $\gamma=1.28$	8 $\gamma=1.39$	9 $\gamma=1.61$
1						x	x	x	x
2				x	x	x	x	x	
3	x	x	x						
4						x	x	x	x
5				x	x	x	x		
6		x	x	x	x				
7	x	x	x						
8						x	x	x	x
9				x	x	x	x		
10		x	x	x	x				
11	x	x	x						
12			x	x	x	x			
13	x	x	x						
14			x	x	x	x			
15	x	x	x						
16			x	x	x	x			
17	x	x	x	x					
18		x	x	x	x				
19	x	x							
20		x	x	x	x	x	x		
21	x	x							
22				x	x	x	x		
23				x	x	x	x		
24				x	x	x	x		
25			x	x	x	x	x	x	
26				x	x	x	x	x	
27			x	x	x	x	x		
28		x	x	x	x	x			
29	x	x	x	x					
30				x	x	x	x	x	
31			x	x	x	x	x	x	
32				x	x	x	x		
33					x	x	x	x	x
34				x	x	x	x	x	
35					x	x	x	x	x
36			x	x	x	x	x		
37			x	x	x	x	x	x	

was begun, it was soon found that it was quite unnecessary to make prints from each of the nine negatives available on all of

the various printing papers chosen. The range of contrast in the group of negatives was far beyond that which can possibly be taken care of by any single paper. The procedure adopted, therefore, was to use a group of negatives in which the most contrasty was obviously much too hard in quality for the paper being used, while the least contrasty was obviously too soft to give a good quality print. In Table X are indicated the negatives which were used in making the prints on the various papers; the numbers in the first column designate the printing papers, those at the top the negatives; an asterisk at the intersection of the *paper* and *negative* columns indicates that prints were made on that paper from that negative.

It has been found that the printing time required to give the best quality of print from a specified negative is, to a certain extent, a question of personal taste or judgment. In order to satisfy such differences of opinion, and also to show the effect of more or less printing exposure, it was decided to make three prints from each negative used. One print was made with the printing exposure such that the resulting print, in the opinion of the author, was of the best quality possible to obtain by the use of the particular negative and paper under consideration. This will be termed the *normal* print. One print was then made with a shorter printing time resulting in a print just perceptibly lighter than the former. The third print was made which was just perceptibly darker. The three prints may be referred to for convenience as *light, normal,* and *dark.*

Development of the prints was carried out in a solution compounded according to the formula recommended by the manufacturer of the paper and maintained at a constant temperature of 20° C. The choice of development time was given serious consideration as this particular point has a profound bearing upon the contrast of the various materials. As was shown in a previous paper,[1] the shape of the characteristic curve of a developing-out paper depends very much upon the extent to which development is carried and this dependence varies greatly for different types of papers. As was shown previously (*loc. cit.*) a paper of the Velox type (when the developer as recommended is used) develops very rapidly, the maximum black and maximum gamma being attained in a very short time (15 to 45 seconds), after which the curve shifts to the left without any appreciable altera-

tion in shape. Since contrast is a function only of the shape of the characteristic curve, this means that this particular material, after a short period of development, suffers practically no change in contrast. As an opposite extreme a bromide paper may be taken. In this case gamma increases at a relatively low rate and maximum black is only attained after a relatively long time of development (3 to 5 minutes). This means that the contrast of such a material changes continuously over a development period of considerable length. Other papers, such as Artura Iris, occupy a place intermediate between the two examples mentioned and the shape of the curve changes over a considerable length of development time. It is obvious from a consideration of these facts that contrast is profoundly influenced by the extent to which the paper is developed, and any specification of contrast must apply to a particular development time and is not complete without adequate specifications of the extent to which development is carried.

In practical work the development time allowed is frequently insufficient to give the maximum gamma and maximum density. From the standpoint of this work, it was thought advisable to use development times sufficiently long to result in *complete* development. This condition of *complete* development is somewhat difficult to define, but for practical purposes may be specified as the minimum development time resulting in the maximum density and maximum gamma obtainable. If development be continued beyond this point, there is, in general, a period over which no further change in shape of the characteristic curve occurs. If the development time be prolonged excessively, fog will begin to appear, but there is, in almost all cases, an appreciable interval between the attainment of a fixed shape and the appearance of excessive fog during which contrast does not change with development time. It seems logical, in attempting to reach a specification of contrast, to require that development be carried into this region where contrast will be but slightly influenced by time of development. Since it is desired to correlate the results obtained by the statistical method with the sensitometric characteristics of a paper, sensitometric strips cut from sheets of paper taken from the same packages as those used in making the prints were exposed in the sensitometer and developed under conditions identical to those used in making the prints. The density values on these strips were measured under the conditions laid down in the previous paper [1]

and the results will be presented later in the section dealing with the sensitometric treatment.

Conditions for Inspection of Positives.—Prints from all of the papers listed in Table IX having been made, the next step was the decision as to which negative produced the best print on each of the thirty-seven papers under test. Preliminary attempts to judge print quality revealed the importance of constant and favorable lighting conditions under which the prints were exam-

FIG. 12.

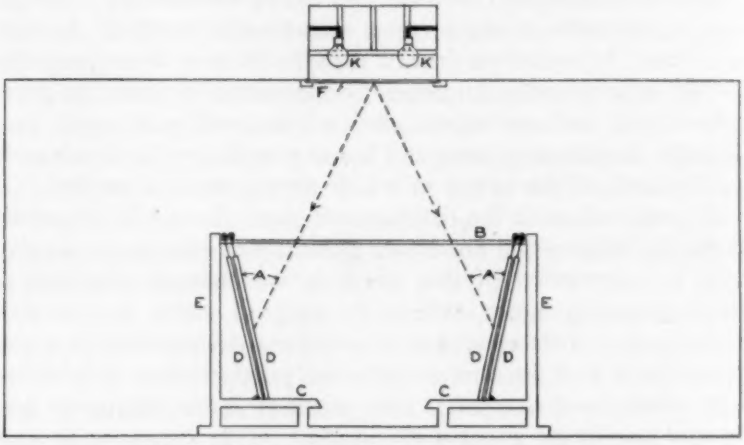


Diagram of display rack on which prints were mounted.

ined. On account of the large number of prints to be examined, it was necessary to construct a special display rack on which they could be mounted so as to be seen under the proper illumination, and also to permit a rapid change from group to group in order to expedite the work of examination. Each print was trimmed and mounted on a dull gray matte board of such a size as to leave a margin 1½ inches wide on all sides of the prints. This neutral gray of medium reflecting power was chosen as being the least likely to influence the observer's judgment of print quality.

The mounted prints were then assembled on the panels of the display rack, each group, consisting of prints made on one kind of paper, being isolated as much as possible from other groups. A diagram (side elevation) of the display rack is shown in Fig. 12. The upright end pieces *EE* rising from the framework resting

FIG. 13.

Photograph of one panel of the display rack carrying a complete group of prints.

on the floor, carry a pair of steel rails (1¼ inches cold-roll shafting, *B*), about 14 feet long and separated by a distance of 30 inches. These serve as a track upon which the display frames move back and forth. The display frames, *DD*, etc., consist of compoboard panels covered with burlap and mounted in wooden frames made of 4-inch × 1-inch material. The panels are approximately 6 feet high and accommodate six rows of three prints each, thus making it possible to mount on a single panel the largest group, which consists of eighteen prints. The frames are supported on the metal track by a hanger terminating at the top of a pair of rollers. The lower ends of the frames, when in position for observation, rest upon the supports *CC*. Sixteen panels giving thirty-two mounting surfaces were necessary for the accommodation of the thirty-seven groups of prints to be examined. In Fig. 13 is shown a photograph of one of these panels with the prints mounted thereon.

This rack was placed directly under a skylight of ribbed glass giving a fair degree of diffusion, and in order to diffuse the light still further, the skylight opening was covered with two thicknesses of white mill net (*F*, Fig. 12). In order to supplement the illumination on dull days, two 1000-watt, gas-filled, blue-bulb tungsten lamps, *KK*, were installed in the skylight space above the diffusion cloth. The dimension of the apparatus and the height of the room were such that the prints under observation were illuminated by diffused light incident at approximately 45° (angle *A*), while the plane of the print was approximately normal to the direction of observation (line of sight). The prints were marked only with code numbers so that the observer making the judgment of quality had no information regarding the paper or negative from which the prints had been made. The three prints from one negative were placed side by side in one row, and the contrast of the negative used increased continuously from top to bottom rows of any given group.

This condition of orderly arrangement was maintained throughout the first series of judgments and facilitated to a great extent the choice of the best print. It was suggested that this orderly arrangement might have an undue influence on the observer's choice and that if the prints were presented to the observer in a haphazard way his choice might not fall upon the same print. This was tested by mixing the prints of any one

group and allowing some of the observers to repeat their observations. The results were very gratifying in that in almost all cases the repeatability of choice was good, although it took the observer three or four times as long to sort out from the disarranged group of prints that print which in his opinion exhibited the best photographic quality.

Judgment of Prints.—A satisfactory and reproducible light condition and method of displaying the prints having been obtained, each one of a large number of observers was asked to pick from each group the print which, in his opinion, was made from the negative best suited to that particular paper. He was further asked to express an opinion as to whether or not the best print in the group was the best print that could be produced on that paper, assuming that negatives of slightly different contrast were available. In many cases the observer expressed the opinion that a better print could have been produced by a negative having a gradient intermediate between those actually available. In this case his judgment was regarded as requiring a gamma between the gamma values of the two negatives actually used. In many cases his judgment was to the effect that, had a particular negative been just slightly more or less contrasty, a better print would have been produced. In such cases 25 per cent. was added to or subtracted from the gamma value of the negative from which the most satisfactory print had been made. In this way it was possible in many cases to obtain a finer division on the gamma scale than was actually available in the negatives themselves. Each observer in this manner indicated for each printing paper the gamma of the negative which, according to his judgment, would produce the most satisfactory print.

Observers and Their Classification.—Prints were examined by seventy-five observers, and since it was desired to determine the effect of previous experience upon the quality of the print selected, the qualifications of these observers varied from the most inexperienced amateur to the most expert judge of print quality. In the analysis of the data obtained, it seemed advisable to divide the observers into three general classes as follows:

Class *A* (professionals). Those having had extensive previous experience in the judgment of the quality of photographic prints, such as those engaged in the manufacture of photographic plates and papers, and those having used such materials in professional work.

Class *B* (semi-professionals). Those having had some experience in the use of photographic materials and judgment of print quality but not so extensively trained as the members of Class *A*.

Class *C* (amateurs). Those having had very little previous experience or education in the judgment of print quality.

In the analysis of results, it was desired to compare the average of the results obtained by each of these three classes of observers. In order to make the mean value for each group depend on the same number of individual observers, the observers were chosen so as to give an equal number in each class. It will be understood, of course, that there can be drawn no distinct line of demarcation between the classification of the three groups of observers. In many cases it was somewhat doubtful in which group to place given observers, but on the average the classification adhered fairly rigidly to the specifications mentioned above.

Repeatability of Values.—Now in the application of statistical methods to any problem, one of the first and most important considerations by which the final decision as to the amount of confidence that can be placed in the results, is that of repeatability, and one of the questions which came up early in this work was relative to this point. It was decided, therefore, to pick a few observers from each of the above classes and to have them make repeat judgments of prints after a lapse of sufficient time, so that there would be little danger of their memory of a former choice having any influence on the choice of prints in the second case.

In Table XI are shown the data obtained by observer No. 3. The values in the column marked 3 are the gamma values of the negative which in his opinion would yield the best print on each of the papers indicated by the number in column *Y*. In column 3*a* are similar values obtained by the same observer at a much later date. In the column *mean* is the average of the two values, and in the column $\Delta\gamma$ are the deviations from the mean value. At the bottom of the table are the mean values of the thirty-seven groups; the mean deviation when expressed as a percentage is 6.6. This indicates that this particular observer was able, after a lapse of considerable time, to repeat his first judgment with a deviation of only 6.6 per cent.

In Table XII is presented a summary of the repeated readings for ten different observers. In the columns under the general

heading *Mean* γ_n (p) are the average negative γ values obtained by each observer in his first and second sets of observations, and

TABLE XI.

Values of Optimal Negative Gamma Obtained by the Same Observer at Widely Different Times, Illustrating the Repeatability of Such Determinations by a Single Observer.

γ	γ_n (p).				γ	γ_n (p).			
No.	3	3a	Mean.	$\Delta\gamma$	No.	3	3a	Mean.	$\Delta\gamma$
1	1.39	1.28	1.34	.11	21	.41	.41	.41	.00
2	1.17	1.17	1.17	.00	22	1.17	1.00	1.08	.17
3	.62	.62	.62	.00	23	1.17	1.28	1.22	.11
4	1.20	1.17	1.18	.03	24	1.17	1.22	1.20	.05
5	1.08	1.08	1.08	.00	25	1.17	1.22	1.20	.05
6	.73	.73	.73	.00	26	1.28	1.22	1.25	.06
7	.57	.51	.54	.06	27	1.11	1.00	1.05	.11
8	1.28	1.22	1.25	.06	28	.84	.84	.84	.00
9	.84	1.00	.97	.16	29	.73	.54	.64	.19
10	.73	.68	.70	.05	30	1.28	1.17	1.22	.11
11	.46	.46	.46	.00	31	1.17	1.17	1.17	.00
12	.95	.84	.90	.11	32	1.08	1.00	1.04	.08
13	.46	.41	.44	.05	33	1.39	1.39	1.39	.00
14	1.17	1.22	1.20	.05	34	1.17	1.17	1.17	.00
15	.73	.73	.73	.00	35	1.39	1.17	1.28	.22
16	1.17	1.00	1.08	.17	36	1.00	1.00	1.00	.00
17	.70	.57	.64	.13	37	1.28	1.28	1.28	.00
18	.84	.78	.81	.06					
19	.46	.46	.46	.00	Mean	.988	.952	.970	.061
20	1.25	1.17	1.21	.08					6.6 %

TABLE XII.

The Values of Mean Optimal Negative Gamma Obtained by a Group of Observers Each of Whom Made Independent Judgments at Widely Different Times, Illustrating the Repeatability of Values Determined in This Manner.

Obs.	Class.	Mean γ_n (p).			Deviations $(\Delta\gamma)$.				
		1st.	2nd.	Mean.	—	+	Total.	Mean.	Mean %.
2	*A*	.962	.945	.954	122	82	204	5.5	5.8
3	*A*	.988	.952	.970	182	44	226	6.1	6.3
4	*A*	.813	.845	.829	26	149	175	4.7	5.8
7	*B*	.867	.847	.857	102	29	131	3.5	4.1
9	*B*	.860	.792	.826	252	11	263	4.4	5.3
11	*B*	.872	.876	.874	55	67	122	3.3	3.8
14	*B*	.869	.793	.831	268	16	284	7.7	9.3
22	*C*	.862	.854	.858	115	99	214	5.8	6.8
26	*C*	.846	.885	.866	93	254	347	9.3	10.7
30	*C*	.977	.980	.978	77	88	165	4.5	4.4
Mean									6.2

the mean of these average values. In the columns *Deviation* $(\Delta\gamma)$ are the total plus and minus deviations from the mean, and the mean deviations expressed both in terms of γ itself and as the

percentage of the mean γ. It will be noted that these values vary from 3.8 per cent. to 10.7 per cent., and for the ten observers who made repeated judgments the mean deviation is 6.2 per cent. The results of these repeated tests indicate that the observer's judgment as to what he considers to be good photographic quality is very definite. It is also of interest to note that the percentage deviations of the observers in Class *A* are of practically the same magnitude as those of Classes *B* and *C*. We must conclude from this that the criterion of photographic quality is no more consistently maintained by the professional than by the semi-professional and amateur.

Final Results of Statistical Determination of γ_n and DS_n.—The detailed data, representing the judgment of the negative best suited to each of the thirty-seven printing papers by seventy-five observers, constitutes a very extended tabulation and it is not considered advisable to give it all in this paper. However, it is of interest to discuss in detail the values obtained by the twenty-five observers in Class *A*. These data are tabulated in Table XIII. The numbers in the first column designate the papers under consideration; the numbers at the top of the table designate the observers. At the bottom of each column is the mean of all of the gamma values determined by that observer. This mean, of course, has no significance relative to the contrast problem, but does provide interesting information about the characteristics of the observer and his preference in print quality. This will be considered in detail later. At the extreme right of the table in the column *Mean* γ_n are the mean values obtained by averaging the twenty-five values for each of the printing papers under test. These values represent the average opinion of the Class *A* observers as to the negative gamma yielding the best print on these particular printing papers.

In the column $\Delta\gamma_n$ are entered the mean deviations from the mean of the group for each paper. These values are expressed in terms of percentage and were obtained by averaging the values of each observer's deviation from the mean of the group. These values are a measure of the lack of agreement between the various observers of this group as to the negative gamma producing the best print on each paper.

Interpretation of the Results from the Standpoint of Observer's Characteristics.—It is evident now that the data tabu-

TABLE XIII.

The Values of Optimal Negative Gamma as Determined by Each of Twenty-five Observers (Group A) on Each of the Thirty-seven Different Developing-out Papers Used.

Paper.	Observer.								
	1	2	3	4	5	10	13	15	16
1	1.22	1.44	1.34	1.28	1.39	1.39	1.28	1.39	1.39
2	1.17	1.21	1.17	1.10	1.17	1.17	1.17	1.17	1.17
3	.62	.53	.62	.49	.62	.53	.53	.62	.46
4	1.22	1.15	1.19	1.07	1.17	1.17	1.17	1.12	1.17
5	.93	1.00	1.08	.90	1.00	1.17	.84	1.17	1.00
6	.68	.71	.73	.56	.73	.68	.62	.84	.62
7	.51	.51	.53	.51	.53	.62	.53	.62	.46
8	1.22	1.17	1.26	1.17	1.28	1.17	1.17	1.39	1.28
9	.84	.84	.93	.84	1.00	.84	.84	1.17	1.00
10	.62	.56	.71	.56	.62	.73	.62	.62	.62
11	.46	.46	.46	.41	.46	.46	.46	.46	.46
12	.73	.78	.90	.71	.73	.84	1.00	.73	.73
13	.42	.44	.42	.44	.46	.46	.46	.46	.46
14	.78	1.08	1.19	.97	.84	.84	.93	1.00	1.00
15	.68	.62	.73	.75	.62	.62	.68	.73	.62
16	.73	1.02	1.08	.82	1.00	.84	1.00	1.00	1.00
17	.62	.62	.63	.51	.62	.62	.73	.62	.62
18	.78	.78	.82	.62	.73	.73	.73	.73	.73
19	.42	.46	.46	.39	.46	.46	.40	.46	.46
20	1.00	1.17	1.21	.96	1.17	1.00	1.00	1.00	1.17
21	.38	.39	.40	.38	.40	.40	.40	.38	.40
22	.95	1.17	1.08	.93	1.00	1.00	1.00	1.00	1.00
23	1.17	1.22	1.22	1.10	1.17	1.17	1.17	1.17	1.28
24	1.17	1.19	1.19	1.13	1.17	1.17	1.17	1.00	1.17
25	.93	1.19	1.19	1.00	1.17	1.08	1.00	1.00	1.00
26	1.22	1.22	1.26	1.13	1.17	1.00	1.00	1.17	1.17
27	.93	1.00	1.06	.73	.84	.84	1.00	.73	.84
28	.73	.93	.84	.73	.73	.73	.73	.84	.84
29	.62	.47	.63	.46	.62	.46	.53	.68	.62
30	1.08	1.19	1.22	.97	1.17	1.08	1.17	1.17	1.00
31	1.08	1.17	1.17	.94	1.00	1.00	1.17	1.00	1.00
32	1.00	1.17	1.04	.84	1.17	1.00	1.17	.84	1.00
33	1.28	1.39	1.39	1.19	1.39	1.17	1.39	1.17	1.39
34	1.08	1.22	1.17	.97	1.00	1.00	1.12	1.08	1.17
35	1.22	1.34	1.39	1.08	1.17	1.17	1.39	1.17	1.28
36	.93	1.17	1.00	.84	.84	.93	1.00	.95	.84
37	1.08	1.17	1.39	1.08	1.17	1.00	1.17	1.17	1.17
Mean	.87	.95	.97	.83	.92	.88	.92	.92	.91
	−.03	+.05	+.07	−.07	+.02	−.02	+.02	+.02	+.01

TABLE XIII—*Continued.*

Paper.	Observer.								
	24	25	28	29	40	42	44	49	12
1	1.39	1.39	1.39	1.17	1.17	1.17	1.17	1.39	1.39
2	1.17	1.28	1.17	1.00	1.08	1.08	1.00	1.17	1.08
3	.62	.62	.56	.46	.62	.53	.46	.56	.62
4	1.17	1.17	1.17	1.08	1.17	1.00	1.17	1.17	1.17
5	1.17	1.17	1.00	.84	1.00	.93	.93	.84	1.00
6	.73	.73	.73	.62	.73	.62	.68	.73	.73
7	.62	.46	.53	.46	.53	.46	.53	.51	.62
8	1.39	1.28	1.39	1.17	1.28	1.17	1.22	1.28	1.39
9	1.17	1.00	1.00	.84	.93	.84	.93	.84	1.00
10	.62	.62	.73	.62	.68	.62	.73	.62	.62
11	.46	.46	.46	.46	.46	.40	.40	.46	.46
12	1.00	.84	.84	.72	.84	.73	.84	.84	.84
13	.62	.46	.51	.46	.51	.46	.51	.46	.40
14	1.00	1.00	1.00	.73	1.00	.93	.93	.84	1.17
15	.62	.73	.68	.62	.62	.73	.68	.62	.73
16	1.00	.84	1.00	.73	.95	1.00	.84	.84	1.00
17	.73	.62	.62	.62	.62	.62	.62	.62	.62
18	.73	.62	.84	.62	.84	.68	.68	.73	.73
19	.46	.46	.46	.46	.46	.46	.46	.40	.40
20	1.00	1.17	1.00	.84	1.17	1.08	.84	1.00	1.00
21	.40	.46	.40	.34	.40	.40	.38	.40	.40
22	1.00	1.00	1.17	.84	1.08	1.00	.84	.84	1.00
23	1.00	1.17	1.17	1.00	1.17	1.17	1.00	1.17	1.17
24	1.17	1.17	1.17	1.00	1.17	1.17	1.07	1.00	1.17
25	1.17	1.17	1.28	.73	1.00	.84	1.00	1.00	1.00
26	1.17	1.17	1.28	1.00	1.12	1.17	1.17	1.17	1.17
27	.95	.84	1.00	.73	.78	.73	.93	.73	.73
28	.84	.84	.93	.62	.84	.84	.73	.73	.93
29	.62	.46	.62	.46	.62	.46	.46	.46	.46
30	1.00	1.17	1.17	.84	1.08	1.08	1.00	1.17	1.17
31	1.08	1.17	1.17	.84	1.17	1.08	1.00	1.00	1.17
32	1.00	1.17	1.17	.84	1.17	1.08	1.00	1.00	1.00
33	1.17	1.39	1.39	1.17	1.28	1.28	1.17	1.28	1.34
34	1.17	1.17	1.17	1.00	1.17	1.17	1.00	1.17	1.17
35	1.17	1.39	1.28	1.08	1.08	1.22	1.17	1.17	1.17
36	1.00	1.00	1.00	.73	1.08	1.00	.93	1.00	.84
37	1.00	1.00	1.00	.84	1.22	1.17	1.08	1.17	1.17
Mean	.94	.94	.96	.77	.92	.87	.85	.87	.92
	+.04	+.04	+.06	−.13	+.02	+.03	−.05	−.03	+.02

TABLE XIII—*Continued.*

Paper.	Observer.								
	43	52	62	58	64	67	73	Mean γ_R.	$\Delta\gamma_R$(%).
1	1.28	1.61	1.39	1.39	1.39	1.39	1.22	1.34	7.4
2	1.17	1.17	1.17	1.17	1.28	1.17	1.08	1.15	5.2
3	.62	.62	.62	.56	.62	.62	.46	.56	14.2
4	1.17	1.17	1.17	1.17	1.28	1.17	1.00	1.16	3.6
5	.84	1.17	.93	1.00	1.17	1.17	.84	1.00	12.0
6	.73	.73	.73	.73	.73	.73	.62	.70	9.2
7	.53	.62	.53	.56	.62	.62	.46	.54	13.5
8	1.17	1.39	1.17	1.17	1.39	1.28	1.17	1.26	3.1
9	1.00	1.17	1.00	.84	1.17	1.00	.84	.95	7.2
10	.73	.62	.62	.62	.73	.68	.62	.64	9.2
11	.46	.62	.53	.46	.46	.46	.46	.46	5.8
12	.73	1.00	.84	.73	1.00	.84	.73	.81	12.7
13	.46	.46	.46	.46	.46	.46	.53	.47	10.0
14	.73	1.00	.84	.84	1.00	1.00	.84	.94	12.9
15	.68	.73	.73	.62	.62	.62	.62	.66	11.6
16	.73	1.00	.84	.73	1.00	1.00	.84	.92	14.1
17	.53	.62	.62	.56	.62	.62	.53	.62	5.2
18	.62	.84	.73	.73	.84	.73	.62	.73	9.4
19	.46	.46	.46	.46	.62	.46	.40	.46	7.0
20	.84	1.00	1.17	.84	1.00	.84	.84	1.02	11.5
21	.40	.40	.46	.40	.40	.40	.34	.40	5.8
22	.84	1.17	1.00	.84	1.17	1.00	.93	.99	9.6
23	1.17	1.17	1.17	1.00	1.22	1.17	1.00	1.15	6.0
24	1.00	1.17	1.17	1.00	1.17	1.17	1.00	1.12	6.6
25	.73	1.28	1.00	1.00	1.22	1.00	.84	.99	13.9
26	1.00	1.17	1.17	1.00	1.17	1.00	1.00	1.14	7.5
27	.73	1.00	.84	.73	1.17	.73	.73	.85	16.1
28	.73	1.00	.84	.73	1.00	.73	.73	.80	13.1
29	.46	.73	.46	.46	.73	.73	.46	.54	26.6
30	.84	1.17	1.00	1.00	1.28	1.00	1.00	1.08	10.1
31	.73	1.17	1.00	.93	1.17	.84	1.00	1.04	11.6
32	1.00	1.17	1.00	.84	1.17	1.00	.84	1.03	11.2
33	1.17	1.39	1.17	1.17	1.39	1.00	1.17	1.27	8.9
34	.84	1.17	1.08	1.84	1.17	1.17	1.17	1.10	9.1
35	1.00	1.08	1.39	1.08	1.39	1.17	1.17	1.21	19.4
36	.73	1.00	.84	.84	1.17	.84	1.00	.94	12.4
37	.84	1.17	1.17	.93	1.28	1.00	1.00	1.12	10.6
Mean	.81	.98	.91	.83	1.00	.88	.82	.90	10.1
	−.09	+.08	+.01	−.07	+.10	−.02	−.08		

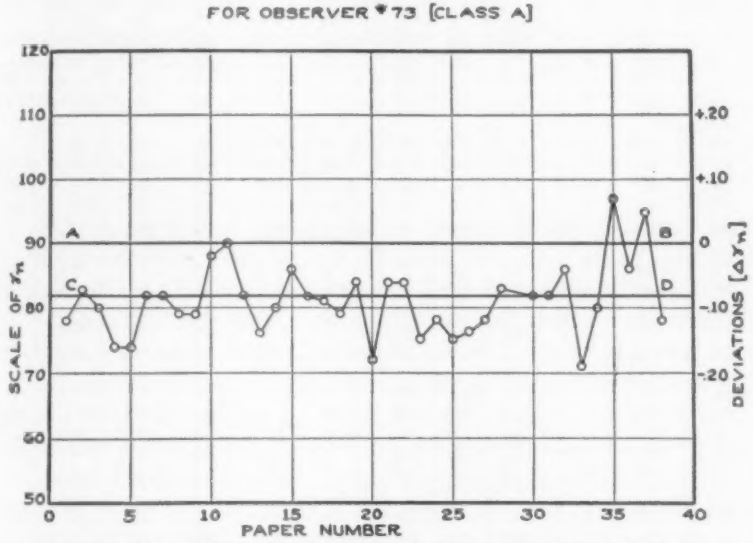
lated in Table XIII afford information not only bearing upon the quality of negative best adapted to each of the printing papers used, but also relative to the characteristics of the observers themselves. Since the confidence which can be placed in results determined by the statistical method of this type must depend upon the characteristics of the observers making the quality judgment, it will be well to consider first the interpretation of the data as bearing upon the peculiarities of the observers. Referring again to Table XIII, let us consider the significance of the mean value at the bottom of each column. Obviously, this value can have no significance relative to the characteristics of the printing papers individually, since this value will depend entirely upon the average characteristics of the particular papers included in the group chosen for test. The value does indicate whether the observer, on the average, has a tendency to choose a contrasty or soft print as compared with the mean quality preferred by the group of observers as a whole. It will be noted that the mean value at the bottom of the column *Mean* γ_n is .90. This indicates that for this particular group of papers the mean γ_n as determined by this particular group of twenty-five observers is .90. Now if some individual observer in the group obtains an average for γ_n of .83 for the same group of papers (Observer 4), it indicates that this observer prefers, on the average, as the best photographic quality, a somewhat less contrasty print than that chosen by the group as a whole. This value then may be taken as an indication of each observer's particular taste or judgment of photographic quality. The characteristic of the observer which causes him to choose prints of a specific quality or contrast will, for convenience, be referred to as his *contrast level* and this contrast level is specified, as far as this particular group of papers is concerned, at the bottom of his column of observations, by the mean γ_n value. This value, then, becomes the observer's *index of contrast level* and for convenience will be designated by the symbol K. Immediately below the mean value for each observer is tabulated the deviation of his *contrast level* from the *contrast level* of the group (.90). These values indicate the magnitude of the disagreement between any particular observer and the average of the group.

There is another type of information relative to the observer which can be deduced from the values in Table XIII. From the standpoint of reliability we are interested not only in whether the

individual observers agree well as to the average quality of negative resulting in the best prints, but also in the observer's ability to maintain a consistent *criterion* of quality. If it be assumed that the mean values of γ_n for the entire group represent the most probable and most satisfactory values which can be established, this series of values can be adopted as a normal against which to evaluate any individual's *instability* of quality criterion.

The method of evaluating this lack of ability to maintain a

FIG. 14.



Curve showing the fluctuation in an observer's criterion of photographic quality.

constant criterion is best illustrated by reference to Fig. 14. At the left-hand side of the figure is established a scale of γ_n and at .90 on this scale the line *AB* is drawn representing the mean level of contrast for the entire Class *A* group. At the right-hand side of the figure is established a scale of deviations ($\Delta\gamma_n$), the zero of this scale being placed coincident with the line *AB*. Now if the deviation between the mean γ_n and the γ_n value for any individual observer be determined for each of the thirty-seven printing papers and plotted in accordance with the deviation scale as established in Fig. 14, the curve connecting the points thus plotted will show the trend of the observer's judgment relative to the normal for the group. Now let the line *CD* be drawn parallel

to the line *AB* at the value represented by the particular observer's *index of contrast level.* In this particular figure, the values plotted are for observer No. 73 (Class *A*) and the deviations

TABLE XIV.

The Index of Contrast Level (K) and the Index of Instability (S) for Each Observer. These Are Grouped under the Three Classifications of Observers so as to Show the Relative Magnitude of These Factors for the Three Types of Observers.

Class *A*.				Class *B*.				Class *C*.			
Obs.	*K*.	△*K*.	*S*.	Obs.	*K*.	△*K*.	*S*.	Obs.	*K*.	△*K*.	*S*.
1	.87	− 3	6.5	7	.85	− 2	6.4	19	.92	+ 2	7.0
2	.95	+ 5	9.9	9	.82	− 5	6.0	20	.84	− 6	9.0
3	.97	+ 7	7.8	11	.87	0	4.3	22	.86	− 4	11.4
4	.83	− 7	6.3	14	.83	− 4	5.3	23	1.04	+14	7.6
5	.92	+ 2	7.0	17	.88	+ 1	8.6	26	.84	− 6	11.5
10	.88	− 2	6.9	18	.89	+ 2	8.6	30	.97	+ 7	5.8
13	.92	+ 2	9.0	21	.73	−14	14.8	37	.94	+ 4	6.1
15	.92	+ 2	8.3	31	.86	− 1	9.8	32	.96	+ 6	8.7
16	.91	+ 1	6.8	36	.77	−10	10.7	33	.86	− 4	10.0
24	.94	+ 4	8.4	39	.91	+ 4	6.3	34	.87	− 3	7.6
25	.94	+ 4	7.2	41	.91	+ 4	9.9	35	1.07	+17	9.3
28	.96	+ 6	6.3	46	.81	− 6	8.6	45	.86	− 4	7.4
29	.77	−13	8.2	51	.92	+ 5	8.8	47	.88	− 2	13.1
40	.92	+ 2	6.7	56	.84	− 3	9.8	48	.89	− 1	10.4
42	.87	− 3	8.7	6	.91	+ 4	10.6	38	1.00	+10	7.5
44	.85	− 5	7.5	55	.93	+ 6	5.6	50	.75	−15	9.8
49	.87	− 3	7.3	60	.80	− 7	7.9	51	.89	− 1	10.7
12	.92	+ 2	7.2	61	.96	+ 9	8.2	63	.87	− 3	12.9
43	.80	−10	14.9	54	.94	+ 7	9.0	59	.89	− 1	13.0
52	.98	+ 8	9.5	27	.92	+ 5	8.6	65	.86	− 4	6.6
62	.91	+ 1	6.1	8	.82	− 5	9.1	66	.97	+ 7	8.5
58	.83	− 7	10.8	53	.89	+ 2	9.1	69	.97	+ 7	10.4
64	1.00	+10	7.9	72	.84	− 3	10.5	70	.89	− 1	7.8
67	.88	− 2	9.2	74	.86	− 1	9.4	68	.80	−10	8.3
73	.82	− 8	7.8	75	.95	+ 8	9.3	71	.92	+ 2	12.7
Mean	.897	4.8	8.1		.868	4.7	8.6		.905	5.6	9.3
Mean %		5.4				5.4				6.2	
Max.	100		14.9		.96		14.8		1.07		13.1
Min.	80		6.1		.77		4.3		.75		5.8
Diff.	20		8.8		.19		10.5		.32		7.3

above and below the line *CD* represent the fluctuations of this particular observer's criterion of quality above and below his own normal. Now if the deviations of the various points from the line *CD* be determined from each of the thirty-seven papers and averaged, the value will be an indication of this observer's ability

to maintain a constant criterion of print quality. This value (mean of the deviations) when expressed as a percentage of the observer's *index of contrast level* may be taken as a direct indication of this observer's *instability of criterion* and the number itself may be designated as the observer's *index of instability* which, for convenience, will be designated by the symbol S.

In Table XIV is given a summary of all of the information bearing directly on the characteristics of the observers of all three classes. In the columns marked K are the *indices of contrast level* for each of the observers, and at the bottom of each of these K columns are shown the *mean index of contrast level* for each group. It is interesting to compare these values for each of the three groups.

For Class A mean $K = .897$.
For Class B mean $K = .868$.
For Class C mean $K = .905$.

It is thought that this agreement is remarkably good and leads to the conclusion that on the average the same print quality is preferred by all three classes of observers regardless of their knowledge and previous training. In the columns $\triangle K$ are the deviations of each of the observer's *contrast level* from the *mean contrast level* of his group. While there are in the case of each class a few deviations of considerable magnitude, the average deviation is remarkably small. This expressed as a percentage is 5.4 for Class A, 5.4 for Class B, and 6.2 for Class C, showing that the certainty with which the negative quality is determined by each of the three classes is practically the same, and therefore that the values of negative γ determined by each of the three classes is equally reliable. In the columns S are the observer's *indices of instability* and here again the values are remarkably small. The *mean index of instability* for Class A is 8.1 per cent.; for Class B, 8.6 per cent.; and for Class C, 9.3 per cent. This shows that on the average the professional class is somewhat more able to maintain a definite criterion of preferred print quality than either of the other two classes, but the difference in this characteristic between the three classes is surprisingly small and again indicates that the mean value of γ_n (where this is used to indicate the quality of the negative which will produce the most satisfactory print on any given paper) determined by twenty-five observers of the amateur or semi-professional class is almost as

reliable and satisfactory as the value based upon the observations of the twenty-five professionals.

In the treatment of any problem by a statistical method, it is necessary to investigate carefully the reliability of the data and the sources from which they are derived. The reader undoubtedly appreciates that, in the last few pages, an attempt has been made to establish confidence in these statistical data and to prove that they are, beyond question, worthy of trust. Their dependability and trustworthiness have been analyzed from four standpoints:

(*a*) Repeatability;
(*b*) Stability of criterion;
(*c*) Agreement between different observers of the same group or type;
(*d*) Agreement between the average values derived from groups composed of observers differing widely in previous knowledge and training in judgment of photographic quality.

The data judged from these standpoints have been shown to be very satisfactory, and the author feels that the agreement between values obtained by observers of different classifications is so good that there is little question as to the reliability of the final results. They show that the value of negative γ required to give the best quality of print on any given printing paper is very definite and quite independent of the character of the observers used in obtaining the value. This, of course, applies to the average obtained from a group of observers containing a fairly large number of individuals. This method would seem, therefore, to be an entirely satisfactory means of obtaining the desired information, and conclusions based upon the results may be considered as thoroughly reliable.

Summary of All Data Relating to the Gradient of Optimal Negatives.—Having analyzed the data from the standpoint of its reliability, we shall now pass to a final summary of the values of *optimal negative gamma* for each of the thirty-seven printing papers used. These values are given in Table XV. In the columns γ_n are the mean values of *optimal negative gamma* for each printing paper, as determined by each of the three classes of observers. In the columns $\Delta\gamma_n$ are the mean percentage deviations applying to these values. In the columns ΔA, ΔB, and ΔC are the percentage deviations of the mean of each group

TABLE XV.

Complete Summary of All Values of Optimal Negative Gamma. The Last Section Contains the Mean Values of γ_n for the Entire Group of Seventy-five Observers.

	Class *A*.			Class *B*.			Class *C*.			Mean of *A*, *B*, and *C*.		
	γ_n.	$\Delta\gamma_n$.	ΔA.	γ_n.	$\Delta\gamma_n$.	ΔB.	γ_n.	$\Delta\gamma_n$.	ΔC.	γ_n.	$\Delta\gamma_n$.	$E(\%)$
1	1.34	7.4	0	1.34	7.0	0	1.34	6.8	0	1.34	7.1	0.7
2	1.15	5.2	+3	1.09	10.4	−3	1.12	11.3	0	1.12	8.9	0.9
3	.56	14.2	−1	.55	19.5	−2	.60	20.0	+3	.57	17.9	1.8
4	1.16	3.6	−2	1.17	1.4	−1	1.20	4.9	+2	1.18	3.3	0.4
5	1.00	12.0	0	.99	9.8	−1	1.02	9.5	+2	1.00	10.4	1.0
6	.70	9.2	−1	.69	14.3	−2	.73	9.2	+2	.71	10.9	1.0
7	.54	13.5	0	.52	18.2	−2	.56	22.9	+2	.54	18.2	1.8
8	1.26	3.1	+2	1.18	6.1	−6	1.27	8.8	+3	1.24	6.0	0.6
9	.95	7.2	+1	.91	11.2	−3	.97	15.3	+3	.94	11.2	1.2
10	.64	9.2	−2	.64	10.1	−2	.71	16.2	+5	.66	11.8	1.1
11	.46	5.8	−1	.47	13.1	0	.48	15.7	+1	.47	11.5	1.2
12	.81	12.7	−1	.80	10.4	−2	.86	8.7	+4	.82	10.6	1.0
13	.47	10.0	−1	.44	10.2	−2	.48	15.4	+2	.46	11.8	1.2
14	.94	12.9	+2	.88	13.1	−4	.93	13.9	+1	.92	13.3	1.3
15	.66	11.6	+2	.63	12.4	−1	.64	9.7	0	.64	11.2	1.2
16	.92	14.1	+1	.88	12.9	−3	.94	13.7	+3	.91	13.6	1.3
17	.62	5.2	+2	.59	19.5	−1	.60	14.0	0	.60	12.9	1.3
18	.73	9.4	+1	.68	13.9	−4	.75	12.0	+3	.72	11.8	1.0
19	.46	7.0	−1	.46	3.4	−1	.49	18.6	+2	.47	9.7	1.2
20	1.02	11.5	+6	.95	17.2	−1	.92	17.5	−4	.96	15.4	1.6
21	.40	5.8	0	.41	11.4	+1	.39	12.7	−1	.40	10.0	1.0
22	.99	9.8	−2	1.00	7.5	−1	1.05	9.7	+4	1.01	9.0	0.9
23	1.15	6.0	+4	1.12	9.1	+1	1.07	11.2	−4	1.11	8.8	0.9
24	1.13	6.6	+2	1.09	11.0	−2	1.12	9.5	+1	1.11	9.0	0.9
25	.99	13.9	−3	1.02	12.1	0	1.06	13.2	+4	1.02	13.1	1.0
26	1.14	7.5	+4	1.08	9.2	−2	1.08	12.0	−2	1.10	9.9	1.2
27	.85	16.1	+2	.78	9.7	−5	.86	15.4	+3	.83	13.7	1.4
28	.81	13.1	+2	.76	12.2	−3	.81	12.5	+2	.79	12.6	1.2
29	.54	26.6	0	.52	21.0	−2	.55	24.4	+1	.54	24.0	2.3
30	1.08	10.1	+1	1.05	12.1	−2	1.07	18.8	0	1.07	13.7	1.4
31	1.04	11.6	+1	.98	10.8	−5	1.08	15.1	+5	1.03	12.5	1.3
32	1.03	11.2	+2	.97	11.2	−4	1.03	11.4	+2	1.01	11.3	1.2
33	1.27	8.9	+2	1.20	8.0	−5	1.28	8.2	+3	1.25	8.4	0.8
34	1.10	9.1	+1	1.05	11.5	−4	1.12	12.1	+3	1.09	10.8	1.1
35	1.21	9.4	−3	1.22	8.0	−2	1.28	10.4	+4	1.24	9.1	0.9
36	.94	12.4	+1	.90	10.1	−3	.95	13.6	+2	.93	14.0	1.3
37	1.12	10.6	+1	1.08	9.6	−3	1.12	14.0	+1	1.11	11.4	1.2
Mean	.90	10.1	1.6	.87	12.0	2.3	.91	13.2	2.3	.89	11.8	1.2

from the mean of the three groups. In the section *Mean of A, B, and C* are the final average values for the entire group of seventy-five observers. In the column designated as $E(\%)$ is

shown the probable error as computed by the method of least squares. These values represent the probable uncertainty in the final value of γ_n obtained by averaging the seventy-five values for each paper. It will be noted that the mean value of this probable error for the entire thirty-seven numbers is 1.2 per cent., which we consider to be remarkably small when the inherent difficulties of obtaining values by this method are considered. The smallness of this probable error indicates that great confidence can be placed in the final values of γ_n as representing the gradient of the negative which will give the best possible rendering of the particular object used in this work on each of the various printing papers.

A study of the data in Table XV shows that the agreement between the results obtained by the three classes of observers is remarkably good. There seems to be little real difference in the average opinion of the three classes as to the negative γ required to produce the best print. The percentage deviation from the mean of a group is about the same for each class. This is illustrated by the mean values at the bottom of the columns $\Delta\gamma_n$ in sections *A*, *B*, and *C* of the table. These mean percentages are:

For Class *A*—10.1%.
For Class *B*—12.0%.
For Class *C*—13.2%.

The values for Classes *B* and *C* are slightly greater than for *A*, but the difference is so small that we are not justified in saying that the determination by one class is appreciably more reliable than that by another class. In applying these values to the determination of the *density scale of the optimal negative* and for further correlation of statistical with sensitometric results, the mean γ_n for all classes will be used. Very little difference in the final conclusions would result from the use of the γ_n values derived from any one of the three groups of observers.

In Table XVI are given the final values of *optimal negative gradient* as determined by the statistical method. In the column $\gamma_n(p)$ are the gamma values as shown in the last section of Table XV. In the column $\gamma_n(v)$ these same values are given in visual terms, the relation being expressed by the equation

$$\gamma_n(v) \cdot \chi = \gamma_n(p) .$$

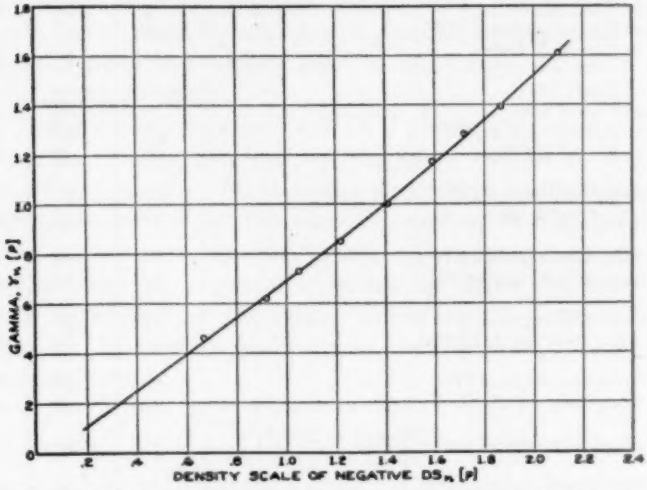
TABLE XVI.

Values of Optimal Negative Gamma (Expressed in Visual [$\gamma_n(v)$] and Photographic [$\gamma_n(p)$] Units) for Each of the Developing-out Papers.

No.	Paper.	$\gamma_n(v)$.	$\gamma_n(p)$.	$\frac{1}{\gamma_n(p)}$.
1	Azo A soft DW	1.10	1.34	.75
2	Azo A hard DW	.92	1.12	.89
3	Azo A hard X DW	.47	.57	1.75
4	Azo E soft DW	.97	1.18	.78
5	Azo E hard DW	.82	1.00	1.00
6	Azo E hard medium DW	.58	.71	1.41
7	Azo E hard X DW	.44	.54	1.85
8	Azo F soft SW	1.02	1.24	.81
9	Azo F hard SW	.77	.94	1.06
10	Azo F hard medium SW	.54	.66	1.51
11	Azo F hard X SW	.39	.47	2.12
12	Azo K hard medium SW	.67	.82	1.22
13	Azo K hard X SW	.38	.46	2.17
14	Velox carbon special SW	.75	.92	1.09
15	Velox carbon regular SW	.52	.64	1.56
16	Velox velvet special DW	.75	.91	1.10
17	Velox velvet regular DW	.49	.60	1.66
18	Velox glossy special DW	.59	.72	1.39
19	Velox glossy regular DW	.39	.47	2.12
20	Velox velvet special portrait DW	.79	.96	1.04
21	Velox velvet contrast DW	.33	.40	2.50
22	Artura iris A	.83	1.01	.99
23	Artura iris E (smooth)	.91	1.11	.90
24	Artura iris D	.91	1.11	.90
25	Artura iris ægis No. 1	.84	1.02	.98
26	Artura chloride smooth DW	.90	1.10	.91
27	Artura non-curling satin soft	.68	.83	1.21
28	Artura non-curling satin medium	.65	.79	1.27
29	Artura non-curling satin hard	.44	.54	1.85
30	Artura carbon black matte	.88	1.07	.93
31	Artura carbon black studio special	.85	1.03	.97
32	Artura carbon black glossy	.83	1.01	.99
33	Bromide BB	1.02	1.25	.80
34	Bromide EP velvet	.89	1.09	.92
35	Bromide EP royal rough	1.02	1.24	.81
36	Bromide EP enameled	.76	.93	1.07
37	Bromide EP matte enameled	.91	1.11	.90

For some purposes, in the sections on correlation to follow, it is convenient to have available the reciprocals of $\gamma_n(p)$ and these are found in the last column of Table XVI. The values in this table represent the final product of the statistical study. The application of these to the determination of *contrast* and to the establishment of definite relations between the characteristics of negative and positive materials, required for the production

FIG. 15.



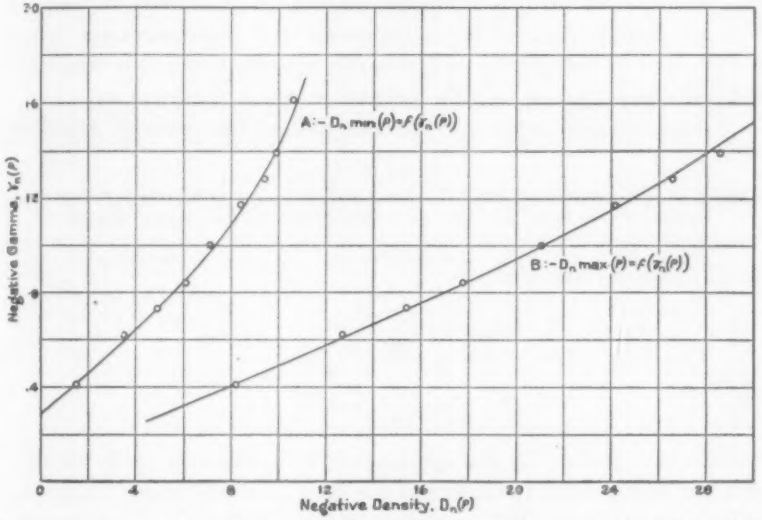
Curve showing relation between the photographic gamma and density scale of negatives, being used to find the gamma of the optimal negatives.

of satisfactory photographic quality, will be treated in a later section.

Further Data Derived from the Optimal Negatives and Positives.—Since it is planned in a later part of this paper to attempt a correlation of these statistical values with the sensitometric constants of the papers, it is necessary to have available some further information relative to the *optimal negatives* and *optimal positives.* These values which must be derived directly from measurements made on the optimal negatives and positives, as determined by statistical methods, are essentially of a statistical type, and for the sake of rational classification it seems advisable to present them at this place. The values tabulated in Table XVI and designated as $\gamma_n(p)$ are the photographic gradients of the *optimal negatives;* that is the negatives which,

according to the average judgment of the seventy-five observers, would produce the best possible print, *optimal positive,* on each of the printing papers used. These values in many cases represent negatives which do not in reality exist. This, of course, follows as the result of the averaging of a large number of gamma values and of the interpolation of gamma values between those of the actual negatives. In Table VI are given the various characteristics of the negatives actually used. For the purpose of correlating the statistical with the sensitometric data, similar

FIG. 16.



Curves used for the determination of the maximum and minimum density values of the optimal negatives.

values for the *optimal negatives* are required. These can be obtained by a process of graphic interpolation between the values applying to the *actual* negatives as shown in Table VI. For instance, in order to find the values of *density scale,* DS_n, for each of the *optimal negatives,* it is only necessary to plot the curve showing the relation between $\gamma_n(p)$ and $DS_n(p)$ from the values tabulated in Table VI. This curve is shown in Fig. 15. Now for each *optimal negative* it is possible to read off the values of $DS_n(p)$ corresponding to the values of γ_n as tabulated in the second column of Table XVI. The numbers thus obtained are shown in the fourth column of Table XVIII.

In a similar way the values of D_n max. and D_n min. may be determined by use of the curves shown in Fig. 16. These are plotted from the data in Table VI and show the values of maximum and minimum negative density plotted as functions of the negative gamma, $\gamma_n(p)$. From the values of optimal negative gamma as given in Table XVI, it is now possible to determine the maximum and minimum density for each of the optimal negatives. These values are shown in the second and third columns in Table XVIII.

Likewise the values of density in the optimal negatives for each of the measured object points, as indicated in Fig. 9, may be determined. These, however, are required only when it is desired to completely evaluate the tone reproduction obtained, and for the purposes of this discussion are not necessary.

There are also certain characteristics of the *optimal positives*

TABLE XVII.

Example of Interpolation to Find D_p max. and D_p min. for Optimal Prints from Values of D_p max. and D_p min. Measured on the Actual Prints.

Group.	Optimal Negative γ_n.	Actual Negative γ_n.	Actual Prints.			Optimal Reprints.		
			No.	D (max.).	D (min.).	D_p (max.).	D_p (min.).	DS_p.
8	1.24	1.17	862	1.45	.12	1.51	.07	1.44
		1.28	872	1.55	.04			
Difference:		.11		.10	.08			

which are necessary in the correlation to follow, the term *optimal positive* being used to indicate the best possible print, from the standpoint of correct exposure, that can be made from the *optimal negatives*. Since the statistical results in some cases call for *optimal negatives* having a gradient intermediate in value between two of the *actual negatives* used, it follows that in such cases it was impossible to make the *optimal positives*, hence it is necessary to determine the characteristics (maximum and minimum density, density scale, etc.) of the *optimal positives* by interpolation from the measured values of positives made from the two negatives which have gradient values nearest to (higher and lower) that required by the *optimal negative*. This interpolation process is illustrated by a specific example in Table XVII. Taking paper No. 8 as a typical case, it will be found by reference to Table XVI that the gamma of the optimal negative is 1.24.

TABLE XVIII.

Various Sensitometric Values Relating to the Optimal Negatives and Optimal Positives.

Paper No.	Optimal Negatives.				Optimal Positives.		
	D_n max.	D_n min.	DS_n.	γ_n.	D_p max.	D_p min.	DS_p.
1	2.72	.92	1.80	1.34	1.12	.07	1.05
2	2.35	.80	1.55	1.12	1.16	.10	1.06
3	1.18	.34	.84	.57	1.17	.12	1.05
4	2.46	.84	1.62	1.18	1.38	.07	1.31
5	2.12	.72	1.40	1.00	1.36	.10	1.26
6	1.51	.48	1.03	.71	1.38	.12	1.26
7	1.09	.29	.80	.54	1.35	.15	1.20
8	2.56	.87	1.69	1.24	1.50	.07	1.43
9	2.00	.67	1.33	.94	1.57	.13	1.44
10	1.39	.43	.96	.66	1.56	.16	1.41
11	.93	.24	.69	.46	1.57	.18	1.38
12	1.75	.58	1.17	.82	1.57	.13	1.44
13	.93	.24	.69	.46	1.50	.16	1.34
14	1.96	.66	1.30	.92	1.18	.05	1.13
15	1.35	.42	.93	.64	1.12	.08	1.04
16	1.94	.65	1.29	.91	1.43	.08	1.35
17	1.25	.37	.88	.60	1.35	.11	1.24
18	1.53	.49	1.04	.72	1.50	.09	1.41
19	.95	.25	.70	.47	1.50	.14	1.36
20	2.04	.69	1.35	.96	1.14	.06	1.08
21	.79	.19	.60	.40	1.46	.14	1.32
22	2.14	.72	1.42	1.01	1.45	.08	1.37
23	2.33	.80	1.53	1.11	1.16	.05	1.11
24	2.33	.80	1.53	1.11	1.17	.07	1.10
25	2.16	.73	1.43	1.02	1.18	.08	1.10
26	2.31	.79	1.52	1.10	1.12	.04	1.08
27	1.77	.58	1.19	.83	1.40	.08	1.32
28	1.69	.56	1.13	.79	1.46	.14	1.32
29	1.11	.31	.80	.54	1.48	.16	1.32
30	2.25	.76	1.49	1.07	1.25	.12	1.13
31	2.18	.74	1.44	1.03	1.33	.12	1.21
32	2.14	.72	1.42	1.01	1.38	.13	1.25
33	2.58	.88	1.70	1.25	1.14	.04	1.10
34	2.29	.78	1.51	1.09	1.45	.09	1.36
35	2.56	.87	1.69	1.24	1.26	.08	1.18
36	1.98	.67	1.31	.93	1.50	.11	1.39
37	2.33	.80	1.53	1.11	1.15	.08	1.07

The gammas of the actual negatives between which this optimal value lies are 1.17 (for negative No. 6) and 1.28 (for negative No. 7). The difference between these two values is .11. The optimal negatives, therefore, lie between negatives Nos. 6 and 7, slightly nearer to No. 7, as indicated by the fraction 7/11. Actual prints are available made from Nos. 6 and 7 on paper No. 8. Density measurements were made on these prints at the points showing maximum and minimum density, these points corresponding to those indicated in Fig. 9 by the numbers 1 and 14. The measurements of maximum and minimum density for the two prints concerned are shown in Table XVII under the heading "actual prints." The difference between the maximum densities of the two prints is .10 and between the minimum densities .08. Using the interpolation factor 7/11, the maximum and minimum density of an imaginary print made from the optimal negative can be determined. These values are shown in the column *optimal print*. This interpolation is based on the assumption that the relation between negative density and print density is a straight line function, and since we are concerned in this case with the interpolation over a relatively small range, this assumption is entirely permissible. In this way, the maximum and minimum density values for the optimal print made from each of the optimal negatives were determined and are tabulated in the sixth and seventh columns of Table XVIII under the general heading *optimal positives*. By taking the difference between D_p max. and D_p min., the value of DS_p (the density scale of the optimal positive) is obtained. These values are tabulated in the eighth column of Table XVIII. In many cases the gamma of the optimal negative came very close to the gamma of one of the actual negatives, and in such cases it was only necessary to measure the maximum and minimum densities of the print made from that negative. These actually measured density values now become the maximum and minimum densities of the optimal print. It should be emphasized that the values in Table XVIII are essentially of a statistical character since they are based upon the characteristics of the negatives determined by the statistical method. These values, while they depend upon density measurements, are not derived from the characteristic curve of the photographic materials, and, therefore, cannot be classified as data of sensitometric origin. The use of these

various values in the correlation of sensitometric with statistical conclusions will be treated in a later section.

SUMMARY.

The results obtained in Section *B* may be summarized as follows:

(*a*) The brightness contrast in the object chosen as a "typical landscape" (Fig. 5) was found to be 39, the highest light having a brightness of 2500 millilamberts and the lowest 64 millilamberts.

(*b*) A panchromatic material was used in making the required negatives in order to minimize the distortion of the visual tone relations due to color effects. By developing a series of sensitometric strips the time of development required to give any desired gamma was determined. The curves obtained show that the exposure latitude of this material is 35, which is approximately sufficient for the rendition of the entire object on the straight line portion of the characteristic curve.

(*c*) A group of nine negatives was made, each having identical exposures, the development time being varied to give gamma values ranging from .38 to 1.32. The densitometric characteristics (D max., D min., and γ) of these negatives were determined by density measurements made directly thereon and by density measurements made on sensitometric strips developed with each negative.

(*d*) Using the negatives thus obtained groups of prints were made from the appropriate negatives on thirty-seven different developing-out papers selected to cover the entire range of contrast available in materials of this type.

From the prints made on each developing-out paper judgment was made by seventy-five observers on the negative producing the optimal photographic quality. The data thus obtained have been examined critically, and from it certain conclusions have been drawn relating to the characteristics of the observers, the repeatability of judgments of print quality, and the average photographic quality considered as optimal by observers differing radically in their training for the judgment of print quality.

(*e*) A summary of the statistical data thus obtained is given, from which is obtained the gamma of the optimal negative for each of the developing-out papers used. The probable error

in these values, computed by the method of least squares, is shown to be remarkably small and indicates that these values may be relied upon as truly indicative of the negative quality which will give the best possible print of the particular test-object used in this work on each of the positive materials.

(*f*) From density measurements made directly on the positives, values of maximum and minimum density for the optimal positive are derived, the difference between these giving the density scale for the optimal positives. These values relative to the optimal positives, together with the densitometric measurements relative to the optimal negatives, constitute the data from which, in connection with the sensitometric data to be obtained in the following section, values of contrast for the positive materials are computed.

Determination of Phosphoric Acid.—The determination of phosphorus pentoxide as magnesium ammonium phosphate has been studied by WALLACE MORGAN MCNABB (Thesis, Graduate School, University of Pennsylvania, 1926, 33 pages). Precipitation of magnesium ammonium phosphate was always incomplete in the cold, but was complete from a hot solution in the presence of ammonium acetate. During ignition of magnesium ammonium phosphate to magnesium pyrophosphate, the crucible must be protected from direct contact with the flame, since phosphoric anhydride is lost by volatilization. The following procedure is recommended: Wash the precipitate of magnesium ammonium phosphate off the filter paper into a tarred platinum crucible. Dissolve the particles adhering to the walls of the beaker and to the filter paper, in warm dilute nitric acid, and add the resulting solution to the contents of the crucible. Make the contents alkaline by addition of ammonium hydroxide, evaporate to dryness, and ignite to constant weight. J. S. H.

Chronological Table of American Industrial Chemistry.—CHARLES A. BROWNE (*Ind. and Eng. Chem.*, 1926, **18**, 884–892) has compiled a chronological table of the leading events in the history of industrial chemistry in America from the invention of the cold amalgamation process for the extraction of silver by Medina, of Mexico, in 1567, to the outbreak of the World War in 1914.
J. S. H.

Color of the Trivalent Titanium Ion.—JEAN PICCARD (*Jour. Am. Chem. Soc.*, 1926, **48**, 2295–2297) has shown that the hydrated trivalent titanium ion is colorless. The violet color of solutions of titanium trichloride is due to the presence of molecules of that compound. J. S. H.

THE ATOMIC THEORY AND DISEASE.*

BY

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LIFE in the human body is dependent upon chemical processes, but vital activities cannot be considered to be governed by the rules of a simple chemical system. There exist factors which modify these chemical processes so that stochiometric explanations are not completely satisfying unless qualified. In vital activities, the processes are based upon colloid structure and life may be defined as a continuance of chemical reactions in a colloid medium. For this reason, surface action is of greatest importance and the reactions of colloids, dependent upon the degree of dispersity, go far to explain the processes of colloid protoplasm.

Mechanism is, therefore, as important as chemical reactions. Protoplasm, which is the basis of life, is a colloid, and the unit of protoplasm is the cell. The cell is an acid (or less alkaline, pH 6.2–6.8) colloid particle, surrounded and contained by a semi-permeable cell membrane and exists in an alkaline medium (the blood plasma, pH 7.40). This arrangement is ideal for bio-electric variation and potential differences across a surface, for the acid cell, with its membrane, acts as an electrode reversible to cations. For this reason, surface action is of greatest importance, and Bayliss teaches that enzymes in the human body obey the usual laws of catalytic phenomena, particularly in heterogeneous systems in which the reactions take place at the surfaces of the colloids, and that the reactions are reversible, the equilibrium point being determined by the effective concentration of water. In muscular contraction, for another example, Bernstein has given definite evidence to show that the energy of contraction is surface energy and that the muscles suffer thermal changes peculiar to surface energy. Many other vital phenomena can be explained upon the same basis.

The functioning cells of the body are controlled and regulated by impulses generated by the cells of other organs and conducted to and fro by structures specially evolved for this purpose. This

* Communicated by the Author.

is nerve action, and there are in the human body two nervous systems—the conscious or cerebral system and the vegetative or unconscious system (also called sympathetic, involuntary or autonomic). The cerebral system has to do with voluntary control (or willed activity) and the vegetative system has to do with involuntary action or the unconscious organic processes. The vegetative nervous system controls the heart that beats, the stomach and intestines that move and digest, the kidneys that secrete, and all the varied processes of our unconscious life and without our control. This vegetative system consists of two opposed and balanced parts, the vagus and sympathetic divisions. (The vagus part is also called para-sympathetic and the sympathetic is also called the sacro-lumbar.) The control by the vegetative nervous system is largely effected through its action upon smooth, involuntary, or non-striated muscle in contra-distinction to striated or voluntary muscle, which is controlled by the cerebral or conscious system. Smooth, involuntary, or non-striated muscle is very widely distributed in the body, in the pupil, in the heart, blood-vessels and capillaries (Rouget cells), in the great organs, stomach, intestines, spleen, etc. The vagus division, for example, makes the heart beat slower and the sympathetic division makes the heart beat faster. The vagus makes the stomach and intestines contract, and the sympathetic makes the stomach and intestines dilate, etc.

In the consideration of human life and its deviations in disease, there must then be considered (1) *the application of energy from atoms,* (2) *the colloid character of the protoplasm of the human body and* (3) *the control exercised over these processes by the vegetative nervous system.*

The colloids of the human body are amphoteric (neutral or without potential) until vitalized by electrolytes which give them charge. It is for this reason that the inorganic salts, although comprising only about 2 per cent. of the body-weight, are of supreme importance. These determine the potential, so that the acid cell with its semi-permeable membrane, existing in an alkaline medium, is dependent upon external conditions for the various manifestations of life. Energy production is dependent in these cells upon organization or mechanism and potential differences across a membrane or surface. The energy is the energy of the electrons and dependent, as are the properties of elements, upon

the configuration of electrons, particularly those in the outer layer. Langmuir has shown that it is possible to predict the properties of elements according to the configuration of electrons and that the tendency to give or take electrons is dependent upon the presence of electro-positive or electro-negative elements, capable of taking or giving electrons. Naturally, our knowledge of these forces is at present limited, but, when in the future we are better able to calculate the force between the electrons and the positive nuclei of the atoms, it will be possible to account for all phenomena, physical and chemical, physiological and pathological, by calculating the forces between molecules, electrons and atoms. If these forces are all electrical in their nature, the force holding them together in a chemical compound, like NaCl and the force, binding hemoglobin, or producing consolidation in pneumonia, are of the same nature, and dependent upon the relation of the electrons to the positive nucleus. Univalent substances, like Na and K, with one outer electron, have an action more like each other in the human body and antagonistic to bivalent elements, like Ca and Mg, with two outer electrons.

The cells of the human body act like negative suspensoids, reversible to cations and controlled by the buffer salts and their potential differences are due to traces of electrolytes, exactly as has been shown by Murkerjee in negative suspensoids. Murkerjee has also shown that elements have greater or less adsorbability to negative suspensoids in the order, Th > Al > Ba > Sr > Ca > Mg > H > Cs > Rb > K > Na > Li, and in the human body, the same order, Ca > Mg > K > Na > Li, holds for the production of acidity, blood-pressure and other effects. The Ca and Mg salts produce acid conditions in the blood (plasma pH), urine, stool and other secretions, and the Na and K salts produce alkaline condition. The Ca and Mg salts stimulate the vagus side of the vegetative nervous system and the Na and K salts stimulate the sympathetic part. Murkerjee has, indeed, suggested in a recent paper that the results obtained by the biologists upon unicellular organisms are due to this action, and that, "at least one of the main causes which is responsible for the ionic antagonism as observed by Lillie, Osterhout, Loeb and Clowes is the effect of the ions on the electrical charge of the dispersed system."

Protoplasmic or vital action may then be crudely represented by the following diagram:

Nucleus)	Cation)	Electrolyte)	Protoplasmic
Electron)	Anion)	Water)	Action or
Nucleus)	Colloid)	Colloid cell)	Vital
Electron)	Film)	Cell membrane)	Processes

However, in the human body, control of processes by nerve action is of importance. The smooth muscle of the human body may be taken as an index of the balance of the vegetative nervous system and, as the pupil of the eye dilates with sympathetic action and contracts with vagus action, so the greatest mass of smooth muscle in the body, the stomach and intestines, are similarly influenced. It has been found possible by Ludlum and me by a mass of X-ray pictures and fluoroscopic examinations of the gastro-intestinal tract, to determine the balance of the vegetative nervous system upon the basis of postural tone and haustral arrangement. We also found that when the blood plasma was more acid (lowered pH), there was a tendency to vagus effects and, when the blood plasma was more alkaline (higher pH), there was a tendency to sympathetic effects. These were not only shown in the smooth muscle of the intestine, but upon the heart (blood-pressure and pulse rate) and smooth muscle elsewhere. Here then was a relation between chemical action and body processes, so that, to quote Crozier, the biologist, "typical vital processes obey quantitatively the laws of ordinary chemical dynamics."

We have found that certain diseases, like tetany, etc., arranged themselves upon one or other side of the vegetative nerve balance, so that it has been possible to represent them in the schema on the following page.

It has been possible, therefore, to translate manifestations of disease in terms of vagus-sympathetic balance and, with the aid of hydrogen-ion concentration estimations of the blood plasma, in terms of chemical processes.

Disease may, therefore, be divided into two great classes, (1) *the vagus preponderant* and (2) *the sympathetic preponderant*. In the vagus preponderant, there are symptoms associated with excess of bi- and trivalent cations and anions, increased hydrogen-ion concentration and increased smooth muscle reaction. With these changes must come a decrease of (permeability) and conductivity in the cell, increased tendency toward coalescence, or condensation of the colloid, acidity and oxidation (electron-taking)

Cause.		*Mechanism.*	*Expression.*
Energy from orientation and configuration of electrons in atoms and molecules	Metabolism	Coalescence of colloid	
		Bi- and trivalent cations and anions produce vagus effects	
		Less cell conductivity	
		Less potential difference	
		Anodal	
		Negative	
		Increased smooth muscle reaction	Most infections
Inorganic salts		Lower pH (higher H-ion concentration in blood)	Colitis Typhoid Diabetes
		Less permeable cell membrane	Neurasthenia
		Vagus	
		Plasma less alkaline	
Lipoid solvents		Oxidation	
			Health
Hydrogen-ion concentration		Reduction	Psychasthenia
		Plasma more alkaline	Deficiency disorders
		Sympathetic	Tetany
		More permeable cell membrane	Rickets Syphilis
Oxidation-reduction poise		Higher pH (lower H-ion concentration in blood)	Eclampsia Respiratory infections (Tuberculosis) (Pneumonia)
		Decreased smooth muscle reaction	Gastric ulcer
		Positive	Essential hypertension
		Cathodal	Œdema
		Greater potential difference	
		Greater cell conductivity	
		Univalent cations produce sympathetic effect	
		Dispersion of colloid	

effects. In the sympathetic preponderant diseases, there are symptoms associated with excess of univalent cations (or diminution of the bi- and trivalent cations) decreased hydrogen-ion concentration and decreased smooth muscle reaction. With these

changes must come an increase of (permeability) and conductivity in the cell, increased tendency toward dispersion of the colloid, alkalinity and reduction (electron-giving) effects.

This theory has been applied in treatment to various diseases, as gastric ulcer, etc. An example is in essential hypertension, or high blood-pressure which is controlled by the sympathetic part, and is benefited by the sodium-free diet and by the taking of calcium and magnesium salts. (Abstract sodium—add calcium and magnesium.) The symptoms of disease may be explained upon the basis of this theory.

For example, blood-pressure is a significant and fundamental

Blood-pressure Effects.

Substances Which Decrease Blood-pressure.	Substances Which Increase Blood-pressure.
Vagus Stimulants.	*Sympathetic Stimulants.*
Make urine acid	Make urine alkaline
Make blood plasma less alkaline	Make blood plasma more alkaline
Bi- and trivalent cations and anions, like Ca, Mg and HCl	Univalent cations like Na and K
Decrease (permeability) of cell in biological experiments	Increase permeability of cell
Decrease conductivity	Increase conductivity
Oxidant (takes electrons)	Reductant (gives electrons)
Greater adsorbability to negatively charged surfaces	Less adsorbability to negatively charged surfaces
Make water-in-oil emulsions	Make oil-in-water emulsions (Clowes)

process in the human body and its control is dependent upon the vegetative nervous system of which sympathetic stimulation increases and vagus preponderance decreases the blood-pressure. Hypertension is a sympathetic phenomenon and all substances which reduce blood-pressure are vagus stimulants, such as the calcium and magnesium salts and parathyroid extracts. In the rabbit's heart, Drury and Cowles have found that there was increased rate and conduction (sympathetic effect) with a pH = 7.8 (alkaline side), while at pH = 7.0 (acid side), there was a slowed rate of the heart. This correlation of the heart action and chemical conditions bears out Crozier's statement that "chemical conditions control the activity of the central nervous tissues" and that these include control of the vegetative nervous system which governs metabolism and body processes. Not only does the

degree of hydrogen-ion concentration have an influence, but also the special effects of the various salts.

In the study of blood-pressure, as a prominent and fundamental manifestation, it is found that the action may be represented in parallel columns.

Other symptoms of disease may be explained in a similar fashion. Gastric secretion, which is a function of gastric motility, is increased by vagus-effect-producing substances and decreased by sympathetic-effect-producing substances. Temperature, which is a function of water content, depends for its equilibrium upon the imbibition of the colloid water and structural changes of colloid. Respiration is very definitely controlled by hydrogen-ion concentration and oxidation-reduction poise.

The processes of disease are but deviation from normal protoplasmic processes and these depend upon colloid reactions in an aqueous medium, so must obey the laws of colloid chemistry. In this, the most important principles are surface action, adsorption and disorption, the electrical double layer of Helmholtz, and the effect of the electrical charge of ions. In this must be considered the control of the vegetative nervous system and disease can be divided into two great classes, (1) the vagus preponderant and (2) the sympathetic preponderant. These classes correspond to alteration in the colloid upon one or other side of the normal bio-electric variation or charge. In classification, the hydrogen-ion concentration of the blood and the smooth muscle reaction is of great importance.

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Golden Jubilee of the American Chemical Society.—The American Chemical Society was organized in New York City on April 6, 1876. The semi-centennial of its founding was celebrated at a general meeting of the Society held at Philadelphia, September 6 to 11, 1926. The Society has issued a Golden Jubilee Number of the *Journal of the American Chemical Society* to celebrate the event, and to record "A Half-century of Chemistry in America, 1876–1926." Charles A. Browne has edited the number and written the introduction. The first part is devoted to the origin and development of the American Chemical Society and contains papers by Samuel A. Goldschmidt, William H. Nichols, Frank W. Clarke, Charles E. Monroe, and Charles L. Parsons. The second part is devoted to reviews of progress in various branches of chemistry in America in the past half-century, and contains papers on "Mineral Chemistry," by Edgar F. Smith; "Physical Chemistry," by Wilder D. Bancroft; "Inorganic Chemistry," by James L. Howe; "Organic Chemistry," by Treat B. Johnson; "Chemistry of Physiology and Nutrition," by Graham Lusk; "Agricultural Chemistry," by Charles A. Browne; "Industrial Chemistry," by Charles E. Monroe, and "Chemical Education," by Samuel R. Powers. This special number of the *Journal* contains 254 pages, and is copiously illustrated with pictures of past officers and surviving founders, as well as of the group which celebrated the centennial of the discovery of oxygen by Priestley by a pilgrimage to his grave at Northumberland in 1874.

J. S. H.

Determination of Acidity in the Presence of Certain Aniline Dyes.—C. H. BADGER and J. W. SALE (*Jour. Asso. Official Agri. Chemists*, 1926, **9**, 342–346) have devised a procedure which makes possible the titration of the acids present in a liquid, such as a highly colored flavoring syrup or beverage, which contains permitted coal-tar dyes. If the liquid be boiled with woolen cloth (nun's veiling), in the presence of the acid, the following dyes are almost or completely removed from solution by the fabric: Ponceau 3B, amaranth, orange I, naphthol yellow S, tartrazine, guinea green B, light green SF yellowish, and indigo disulphoacid. Erythrosine precipitates on boiling, and yellow AB and yellow OB are insoluble in water. After removal of the dye, the acid is titrated with standard alkali, using phenolphthalein as an indicator.

J. S. H.

Crystalline Urease.—JAMES B. SUMNER (*Jour. Biol. Chem.*, 1926, **69**, 435–441) has isolated from the jack bean (*Canavalia ensiformis*) a globulin which crystallizes in octahedra and apparently is identical with the enzyme urease. One gram of this protein, acting upon urea in the presence of a suitable phosphate mixture (buffer solution), will produce 100,000 milligrams of ammoniacal nitrogen in five minutes at a temperature of 20° C. At this temperature, the globulin decomposes its own weight of urea in 1.4 seconds.

J. S. H.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

ON VARIATIONS IN THE THRESHOLD SPEED OF AN EMULSION ACCORDING TO THE DEVELOPER AND CONDITIONS OF DEVELOPMENT.[1]

By E. R. Bullock.

For every emulsion, at a given temperature, there is an optimum development time at which the minimum light-exposure is just rendered visible, that is at which the threshold (Schwellenwert) speed of the emulsion is a maximum. For a given slow emulsion the maximum threshold speed is primarily dependent on the actual reducing substance in the developing solution, and is scarcely affected by variation in the concentration of the sulphite, bromide, and other constituents. The various ordinary organic chemical developing agents form a series, of which elon (*p*-methylaminophenol) occupies the highest position, and pyrogallol the lowest. This series bears some resemblance to the Watkin's factor series, but with this marked distinction, that the former is independent of the bromide concentration. The resemblance to the reduction potential series is probably closer, and it is even possible that the two are identical. The threshold speed series is a continuous one, from alkaline chemical developing solutions, in which the actual reducing substance is an anion, to nearly neutral or acid silver-containing physical ones, in which the reducing substance is a cation. For emulsions faster than process, the same sequence probably holds, but the difference between individual chemical developers is usually less and sometimes only of the same order as the experimental uncertainty.

Beyond the optimum time of development, the developed image scale begins to recede, or in other words, the lowest exposure fields of a tablet exposure begin to disappear for visual observation such as before an illuminator, one by one, or the extreme shadow details of a camera exposure are lost, little by little. This effect is seen with every emulsion and every (chemical or physical) developer. It is scarcely appropriate to say that the image becomes lost or buried in fog, for the reasons that the

* Communicated by the Director.

[1] Communication No. 268 from the Research Laboratories of the Eastman Kodak Company and published in *Sci. Ind. Phot.*, **6M**: 33, 41, 1926.

effect persists on increasing the illumination and that with certain emulsions and developers there is a transition of the lowest exposure fields through disappearance to reversal. This reversal belongs to that class of reversal effects designated by Liesegang as pseudo-solarization.

Among incidental results it may be mentioned that, while a higher threshold speed is always found by chemical development than by physical development, there is but little difference between the results by pre-fixation and those by post-fixation physical development, provided that fixation in the latter case is not in hypo but in sodium sulphite solution.

THE STAINING PROPERTIES OF MOTION PICTURE DEVELOPERS.[1]

By J. I. Crabtree and M. L. Dundon.

WHEN developing positive motion picture film by the rack and tank systems it is frequently necessary to discard an otherwise satisfactory developer because of the formation of stain. This stain is usually in the nature of dichroic fog having a metallic silvery appearance, and is not oxidation stain, since the quantity of sulphite in the average elon-hydroquinone developer is sufficient to prevent the accumulation of staining oxidation products.

It has been shown that the silver stain is a result of the presence of both hypo and sodium sulphide in the developer. Hypo accumulates as a result of insufficient washing of the racks after fixing, while the sulphide is formed by the reduction of the sulphite and hypo present in the developer by bacteria or fungi.

The remedy consists of using waterproof racks so as to prevent the transference of hypo, and in sterilizing the tanks before filling with developer.

THE EFFECT OF CONCENTRATION OF SENSITIZER ON SPEED, WITH A NOTE ON FOG CORRECTIONS.[2]

By S. E. Sheppard.

THE variation of speed and the increase of fog with increasing amount of sensitizer is examined. Insensitive film bathed in

[1] Communication No. 271 from the Research Laboratories of the Eastman Kodak Company and published in *Sci. Ind. Phot.*, **6M**: 84, *et seq.*, 1926.

[2] Communication No. 272 from the Research Laboratories of the Eastman Kodak Company and published in *Phot. J.*, **66**: 399, 1926.

allyl thiourea increases in speed from 25 H. and D. to 3800 H. and D. with one part in 6250 of this sensitizer, falling to 800 H. and D. with one part in 200. Fog increases from 0.07 through 0.43 at maximum speed to 2.34 with the 0.5 per cent. sensitizer. Gamma reaches an ill-defined maximum at 2000 H. and D. with one part in 10,000 sensitizer.

Discussing fog corrections the Meidinger-Wilsey equation is compared with that of Nietz. The former supposes the silver deposited as fog is zero only where light exposure is at a maximum. The author favors a Nietz equation of the type $D_f = f(D_i - D_i)$, and suggests that for short development there is no fog deposited with the image resulting above a certain critical exposure.

COLLIMATION OF LIGHT FROM A SOURCE OF FINITE EXTENSION.[4]

By L. Silberstein.

FOR a point-source perfect collimation, with a perfect lens, is obtained by placing the source at the focus of the lens. If, however, the dimensions of the source are not negligible, the emergent rays are inclined to each other and to the optical axis, even if the (flat) source be placed in the focal plane. It then becomes of interest to inquire whether some other position of the light source gives a nearer approach and to actually find the position giving the nearest approach to perfect collimation. This is the object of the paper.

As a numerical measure (D) of the deviation from perfect collimation is defined the mean value of the angle of inclination of the emergent rays to the axis of the optical system, this mean being obtained by averaging first over the rays issuing from a fixed point of the source and then over the whole area of the source or, equivalently, over that of its image. A formula for the deviation D thus defined is constructed for the cause of a disc-shaped source and is discussed in general terms and on a numerical example illustrating the dependence of D upon the distance and the size of the source and upon the effective aperture of the lens. The position of nearest approach to perfect collimation,

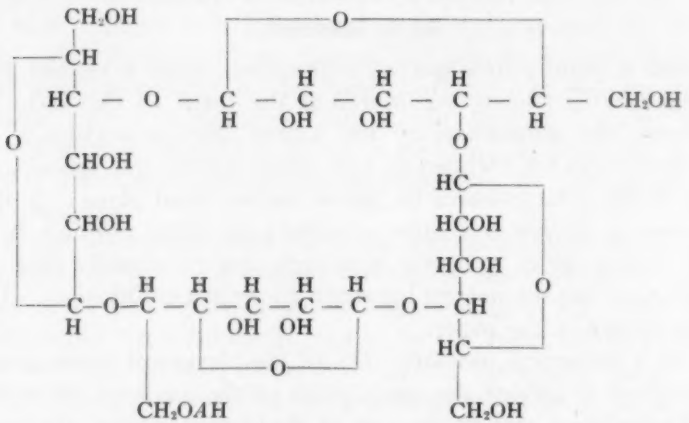
[4] Communication No. 265 from the Research Laboratories of the Eastman Kodak Company and published in *J. Opt. Soc. Amer.*, **13**: 281, 1926.

which turns out to be extra-focal, is determined and the corresponding minimum deviation D is compared numerically with that belonging to the focal and to some other positions of the source.

A SUGGESTED CONSTITUTIONAL FORMULA FOR CELLULOSE.[6]

By H. LeB. Gray.

TO ALIGN the formula for cellulose with the chemical evidence shown by viscose and cellulose xanthoanilide that one hydroxyl per C_{24} is different from the other hydroxyls in the unpolymerized cellulose molecule as well as to align it with the physical evidence of Herzog which indicates $x = 1$, 2, or 4 in $[(C_6H_{10}O_5)_x]_y$, where y is the polymerization or association value, the following formula is submitted:



The hydroxyl marked A is different in its relation to the molecule from the other eleven.

This formula is also in accord with the production of 2, 3, 6-trimethyl glucose. It would postulate a quantitative yield of cellobiose octa-acetate under certain conditions as well as the possible formation of a biose other than cellobiose octa-acetate. The formation of a possible trisaccharide is indicated by this formula.

[6] Communication No. 281 from the Research Laboratories of the Eastman Kodak Company and published in *Ind. Eng. Chem.*, **18**: 811, 1926.

NOTES FROM THE U. S. BUREAU OF MINES.*

MILLING OF FLUORSPAR ORES.

By W. H. Coghill.

IN THE investigation of methods of milling fluorspar ores, the purpose is to determine the best methods and equipment to use, and to obtain data on the principles of ore dressing involved. In the fluorspar district of southern Illinois and Kentucky, the ores are largely fluorspar, silica, and calcite, and as these minerals do not differ greatly in specific gravity, their milling is a difficult problem. Work conducted by bureau engineers in this district, extending over a year, has resulted in changes in nearly every mill there. The system of jigging unsized material in the Tri-state zinc district has been thoroughly studied, and an effort is being made to apply the information obtained to the milling of fluorspar. It was found that the practice of jigging unsized material, as applied to fluorspar ore and tailings, is not economical, and that good sizing before jigging is essential. The losses of fluorspar in the tailings were large, in some mills the tailings contained as much as 25 per cent. fluorspar. Radical changes in the construction of the jigs used were recommended by the bureau engineers, and they assisted in installing changes in the jigs at four large mills that resulted in marked improvement in the work of the jigs. The most difficult problem, however, is to save the fluorspar in the fine material, less than 8 or 10 mesh in size, which in the past has been practically all lost in the tailings. After various experiments, the bureau engineers with the coöperation of the mill operators developed a system of jigging, classification, tabling and reclassification that treats successfully material as fine as 100 mesh. As a result, one of the largest fluorspar companies in the district is engaged in remodeling its entire mill in accordance with recommendations of the bureau metallurgists based on this work. The investigative work will be continued with a view to observing the benefits from such alterations, and to assisting mill operators in further improving the methods.

* Communicated by the Director.

OIL-SHALE EXPERIMENTAL PLANT NEAR RULISON, COLORADO.

By M. J. Gavin.

INVESTIGATIONS of the treatment of oil shales conducted by the Bureau of Mines over a period of ten years, in coöperation with the states of Utah and Colorado, and work of other agencies, has aroused much interest in these shales as a commercial source of oil. At the suggestion of the committee appointed by the President to determine the possibilities of a future supply of oil for the Navy, Congress appropriated $90,000 to the Bureau of Mines in March, 1925, for the construction and operation of a pilot oil-shale plant and the purchase and mining of shale. The site selected for the plant is 1½ miles southwest of Rulison, in Garfield County, Colo., on Naval oil-shale reserve No. 3. A 3-mile trail from the plant site to the mine site and a road from Rulison to the plant were constructed by the county road board. An aerial tram line is being erected from the mine to the plant, along a route based on topographical survey made by the United States Geological Survey. The General Land Office coöperated by making a survey for the water supply line to the plant. The town of Rifle, 13 miles from the plant, has donated the use of an office in its high school building. Several plant buildings have been constructed, and the work of installing equipment is practically completed. The plant includes a Pumpherston oil-shale retort purchased in Scotland, an American type retort, scrubbers, condensers, gas producer, water tank, boilers, crushers, a laboratory, and other equipment. The Scotch type of retort was recently placed in operation and the American type retort will probably be started in the latter part of September.

MINE DRAINAGE IN IRON MINES OF ALABAMA.

By W. R. Crane.

AN INVESTIGATION of drainage problems in the red iron ore mines of the Birmingham district in Alabama has been completed. The work comprised a detailed study of rainfall, run-off, source of surface and ground waters, and their entry into the mines. The effects of ground movement and subsidence on the drainage of the surface overlying the mines was also studied. Data were obtained on the relations between all phases of the movement of water on the surface and underground, and the effects of mining

on the natural drainage conditions. With these data in hand, the operators can attack their drainage problems more intelligently and plan more effectively the measures needed to take care of troublesome water.

COAL-ASH FUSIBILITY AS RELATED TO CLINKER FORMATION.

By A. C. Fieldner.

THE Bureau of Mines is conducting, at the Pittsburgh experiment station, tests of the fusibility of coal ash and the relation of such tests to the clinkering characteristics of the coal. While laboratory methods for determining fusibility of ash have been carefully investigated by the bureau and standardized, no comprehensive study has hitherto been made as to how accurately such laboratory tests predict clinker trouble in burning coal. Seven different coals having a wide range of ash fusibility were tested for fusibility by the standard method worked out by the bureau, and by two other well-known methods. The coals were studied as to the distribution and composition of the ash-forming constituents, the sulphur content, and fusibility of ash. Firing tests were made on the same coals in a special hand-fired furnace developed by the bureau engineers. The results of the fusibility tests were found to be indicative of the clinkering trouble that was experienced in burning the coals. The work is being continued on other coals.

SPONTANEOUS COMBUSTION OF COAL.

By J. D. Davis.

LABORATORY studies of the heating characteristics of coal under controlled conditions have been completed. The amount of heat involved in the early stages of initial heating was accurately determined, and fundamental data were obtained on the sensitivities of various coals, and the effects of different physical factors, such as ventilation, flow of heat, and presence of moisture, on the tendency to spontaneous heating. It was found that in coal at normal room temperature (70°F.), the heating action, if any, was too slight to be detected by the most sensitive methods, but from temperatures comparable with a hot day in summer (100°F.) spontaneous heating could be developed with dry coal to the ignition point without external heat being applied, provided adiabatic

conditions were maintained and enough oxygen was supplied. Study of the effect of presence of moisture indicated that moisture may have a warming or cooling effect, depending on whether it is being evaporated from or condensed on the coal. Investigation of extractable constituents in the coal did not show any appreciable difference in their tendency to heat. The general conclusion from the tests was that spontaneous heating of coal in storage is due more to a combination of circumstances favorable to heating than to the effect of any particular constituent in the coal, or to moisture.

PHOTOGRAPHING THE FLAME OF EXPLOSIVES.

By V. C. Allison.

THE flame of a permissible explosive endures less than one-thousandth of a second, hence photographic methods of research are desirable in studying explosives. Chemists of the bureau have developed a new method of measuring the rate of detonation or speed of an explosive, by photographing the flame on a rapidly moving film. Photographs made of the flame in testing charges of explosive fired from a cannon show graphically the increased safety of certain explosives and methods of loading, by the length of flame produced. The photographic recorder has also been used in determining the means by which detonation is propagated from one stick of explosive to another, across an intervening air gap. The method will also be used in obtaining more data on the fundamental principles of the process of ignition of gas and coal dust by explosives.

Solutions of Sodium Hypochlorite.—RALPH LLOYD WELLS (*Am. Jour. Pharm.*, 1926, **98**, 404–406) has studied solutions of sodium hypochlorite and their deterioration. While a solution containing 42 per cent. available chlorine may be prepared, the most concentrated solution on the market contains only 10 per cent. available chlorine. The solutions deteriorate on keeping, the greater the content of available chlorine, the more rapid the deterioration. An excess of alkali is necessary to preserve the solution for even a short time; the excess of alkali may be present either as sodium carbonate or as a mixture of sodium carbonate and sodium hydroxide. Study was also made of the influence of each of a score of substances upon the rate of deterioration of the solution of hypochlorite, but no substance was found which retarded deterioration. J. S. H.

THE FRANKLIN INSTITUTE.

BARTOL RESEARCH FOUNDATION.

THE Bartol Research Laboratories are in full operation with five Fellows, three machinists, a glass blower, and two research assistants. The outlook for the maintenance of researches of high value is bright. The following educational and biographical statements show the character of the men who are engaged in research at the Laboratories.

FELLOWS.

DR. ARTHUR BRAMLEY, first Bartol Research Fellow, was appointed to his Fellowship in September, 1925, and has been reappointed for the current year. He is a graduate of the University of Oregon with the A.B. degree, and holds the degree of Ph.D. in Physics from Princeton University for "Research on Metallic Conduction in Metals." Doctor Bramley has published about fifteen papers on his researches in physics, and during his Fellowship years has been investigating the properties of the dielectric constant of bromine vapor.

WAYNE B. NOTTINGHAM was appointed Bartol Research Fellow and began his work in the Laboratories on September first. After his preliminary training at the high school at Indianapolis, he was graduated from Purdue University with the B.S. degree. He was awarded an M.A. in Physics by Princeton University in June, 1926, after a year of research work in the Palmer Physical Laboratory. He held the Benjamin Franklin Fellowship in Sweden for the year 1920–1921, and did research work on the electric arc at Upsala during that year. He worked at the laboratories of the Bell Telephone Company in New York for nearly four years, and contributed the following papers: "A New Equation for the Static Characteristic of the Normal Electric Arc." "Normal Arc Characteristic Curves: Dependence on Absolute Temperature of Anode." He will continue for the present his work on the electric arc.

JAMES H. BRENNAN began his work as a Bartol Research Fellow on September first. He was graduated from McGill University with the degree of B.S. in Organic Chemical Engineering in May, 1919. After a period of work in the chemical industry, he attended Cambridge University for a year and carried on research work in Physical Chemistry on "The Adsorption of Different Gases by Metallic Catalysts." He went to the University of Paris and carried out research work at the Radium Institute under the supervision of Mme. Pierre Curie. He was awarded the degree of Docteur es Sciences by the University of Paris. During the last year Mr. Brennan was Professor of Chemistry at Manhattan College, New York City.

HEBRERT BRENNAN took up his work at the Bartol Research Foundation on September first. Mr. Brennan, like his brother, was born in Canada and was graduated from McGill University with a degree of B.S. in Chemical Engineering. He was the honor man of his class in various physical and mathematical subjects. He won numerous honors and medals. After a year

of work of a chemical nature in industry he attended Cambridge University, England. The years 1923 to 1925, he was under the supervision of Mme. Curie in Paris and earned the degree of Docteur es Sciences Physique. He was Professor of Chemistry at Manhattan College, New York City, during the last year.

DONALD H. ANDREWS was appointed Bartol Research Fellow in May, but will not take up his research work until October first, because of ill health. He was graduated from the University of California, carried on graduate research work at Yale University, and during the last year has been a research worker in the laboratories of Prof. H. Kamerlingh Onnes, of Leiden, Holland. Mr. Andrews' work has dealt with the specific heats of organic chemical compounds.

RESEARCH ASSISTANTS.

T. N. PANAY, a student at the University of Paris in la Faculté des Sciences, holds the Master of Arts degree from Columbia University, New York. Since December, 1925, he has been working directly under the supervision of Prof. E. P. Adams, of Princeton, and of the Bartol Advisory Committee, on "Electrets." Mr. Panay has withdrawn from the Bartol Laboratories to continue his studies for the Ph.D. degree.

C. DEL ROSARIO is a native of the Philippines and is a graduate of the University of Philippines with the degree of B.S. After serving as an instructor in that University he spent a year at Yale University, where he earned the degree of Master of Science, presenting a thesis on "Velocity Distribution among Thermionic Electrons in Vacuum and in Hydrogen." During the summer months he has been carrying on research at the Bartol Laboratories on the "Pulling of Electrons from Cold Metals." He has returned to Yale University to take up his labors as a Sterling Research Fellow for the current year.

The research work at the Bartol Laboratory is pursued under an Advisory Committee consisting of Prof. W. F. G. Swann, of Yale University, Director of the Sloane Laboratory, and Prof. E. P. Adams, Professor of Mathematical Physics in Princeton University. These two scholars will continue to direct the research work of the Laboratories until a permanent Director is appointed.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, September 8, 1926.)

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NON-RESIDENT.

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NECROLOGY.

Dr. Charles A. Coffin, New York City, N. Y.
Mr. Max Levy, Allenhurst, N. J.
Mr. Oberlin Smith, Bridgeton, N. J.

MEMBERSHIP ACTIVITIES.

Mr. F. R. Wadleigh has resigned as Editor of *Coal and Coal Trade Journal.* He will devote his attention in the future to consulting work on coal, both engineering and economics, and has also been engaged by several large public utilities for work of a permanent nature in connection with their coal supplies.

BOOK REVIEWS.

CHEMISTRY IN THE WORLD'S WORK. By Harrison E. Howe. vii–243 pages, 8vo, illustrated. New York, D. Van Nostrand Company, 1926. Price, $3.

Within the past score of years or so, considerable activity has developed in the way of books devoted to presenting scientific information in a form

intelligible to the general public. Such books meet two requirements. They afford interesting and instructive reading to a large class of persons anxious for trustworthy information, and they serve to show what science is doing in the way of making life more comfortable and more safe. The primary object of science is the discovery of truth; the practical benefits that may flow from knowledge are secondary considerations with the true scientists. The mass of mankind, however, wants benefits. The young chemist who announces the preparation of a hitherto unknown material is apt to be met with such questions as: "Will your compound bleach or dye?" "Can it be used as a substitute for rubber?" This attitude is probably as strongly marked in this country as anywhere. Research for research's sake has been but little encouraged in the United States for many years. Conditions are somewhat changed. The war showed the value of chemistry and its immediately allied sciences. The cessation of obvious peril has naturally caused a slackening of interest in research, but much is still left. Within the past decade the laboratories of this country have produced many very valuable and highly creditable results, and there is good reason to believe that the work will not seriously slacken.

Books, such as that in hand, serve an excellent purpose in awakening interest in science. Making no appeal to the professional worker but setting forth in plain language the salient points of the extended applications of science to industries as well as to communal life, they secure the active support of intelligent people in the establishment of institutions for the prosecutions of pure science with incidental considerations of the practical applications thereof. Fame comes to the worker in pure science; profit to those who develop the practical applications. The latter will generally find pecuniary aid from those who wish to utilize the discoveries; the former must rely on public or private subvention. Maxwell, who demonstrated the existence of the radio waves, and Hertz, who produced them, are but little known outside of scientific circles; others have taken the substantial awards.

Books intended to appeal to the general public must be written in plain language and must show throughout consideration for the applications of the data. The categoric form of the laboratory manual and the rigid style of the text-book must be avoided. A considerable sprinkling of literary method must be introduced. The general reader soon gets out of his depth in scientific literature. It is only a highly educated taste that can enjoy reading articles on relativity, colloids, or hydrogen-ion concentration.

"Chemistry in the World's Work" meets fully the requirements above noted. Apart from the author's large experience in editing *Industrial and Engineering Chemistry*, which has kept him in touch with the applications of chemistry, he has also written other works of somewhat the same type as the volume in hand. It has the literary flavor and lively style that is necessary to such books, and it is a valuable contribution to the subject. Most books for popularizing science of late years have related primarily to chemistry, but the part played by physics must not be overlooked. Attention is called to this fact in the preface, where also it is stated that mathematics has been largely instrumental in the development of physics. Indications seem to be that chemistry may be swallowed by physics and this in turn by mathematics, at least so far as the pure phases of science are concerned, but there will always be a large

amount of work needed in the laboratories where the more recondite principles will be applied only to a limited extent. The assay of silver ore or the examination of viscera for poison will be carried out without reference to the structure of the atom or the existence of isotopes.

The book is liberally illustrated, written in clear language, covers a large field and will be welcome to the public as presenting the value of scientific research and the methods of its development. HENRY LEFFMANN.

THE ENLARGED HEAT DROP TABLES, H. P. GAUGE PRESSURES, L. P. ABSOLUTE PRESSURES. Calculated by Herbert Moss, D.Sc., A.R.C.S., D.I.C., Imperial College of Science and Technology, from the formulæ and enlarged steam tables of Prof. H. L. Callendar, M.A., LL.D., F.R.S. 88 pages, 8vo, cloth. London, Edward Arnold and Company, and New York, Longmans, Green and Company, 1925. Price, $3.75.

Many investigators of note have been occupied with the difficult task of deriving steam tables, which are both in harmony with theoretical considerations and with observed values and may be applied to the conditions of modern steam engineering. The notable achievement of providing such steam tables which are based upon a consistent system of equations has been accomplished under the leadership of Professor Callendar. Among these, tables of the adiabatic heat drop of steam with initial pressures up to 400 lbs. per sq. in. were published for the British Electrical and Allied Manufacturers Association in 1917; the present volume is an extension of these tables. The adiabatic heat drop of one pound of steam is therein tabulated in British Thermal Units for initially dry saturated or superheated steam of pressures from 400 to 2000 lbs. per sq. in. gauge. The final pressure range has also been extended and is from 27 to 29.5 inches of mercury vacuum, corresponding to absolute final pressures of 3 to 0.5 inches of mercury. Additional tables are included for pressures from 50 to 400 lbs. per sq. in. gauge and vacua from 29.2 in. to 29.5 in. These are arranged with the vacuum tables at the higher pressures. Separate tables of heat drop relating to low-pressure steam are given from 14 to 19 lbs. per sq. in. absolute and from 27 in. to 29.5 in. of mercury. A table of correction for barometric height and conversion tables for initial and final pressures and temperatures are also included.

The volume is in excellent form with a convenient thumb index of vacua in inches of mercury. Engineers who deal with the analysis of performance of engines and turbines will doubtless accord to these tables an honored place in their reference equipment. LUCIEN E. PICOLET.

THE MODERN SOAP AND DETERGENT INDUSTRY, VOL. III—THE MANUFACTURE OF GLYCEROL. By Geoffrey Martin, D.Sc. (Lond. and Bristol), Ph.D., F.I.C., M.I.Chem.E., M.I.Struct.Eng. Variously paged, illustrations, 8vo. London, Crosby Lockwood and Son, 1926. Price, 30 sh. net.

This volume is devoted to the manufacture of glycerol. It is a satisfaction to see in a book of British origin the use of the proper term for this important substance. Originally called the "sweet principle of fats," glycerol has become one of the most important products of industrial chemistry, especially in its application to the manufacture of the well-known high explosive. All

chemists know, of course, that it does not preëxist in fats but is formed in the process of saponification. Its original source was the watery residue from soap manufacture. Later the process of decomposition of fats under the influence of high steam was introduced with great advantage as to the character and cost of the product. This method of decomposition has been greatly improved and is now extensively applied. The most recent method of manufacture is that by the fermentation of sugar, a procedure which it is stated was extensively used in Germany during the war when the employment of fats was inadvisable.

The preceding volumes of this work have been reviewed and the present volume, like its predecessors, contains a very large amount of matter of a trustworthy character presented in a most exasperating and arbitrary arrangement, namely, a series of sections which are independently paged. A table of contents is made quite worthless for use by this system. If the author of this book was seeking to give the world something different in the way of a manual of industrial chemistry, he has succeeded, but it is to be hoped no one will follow his example. HENRY LEFFMANN.

INORGANIC QUANTITATIVE CHEMICAL ANALYSIS, A LABORATORY MANUAL FOR COLLEGES. By Wilfred W. Scott, Sc.D., Professor of Chemistry, University of Southern California. vi–178 pages, illustrations, 8vo. Easton, Penna., The Chemical Publishing Company, 1926. Price, $2.50.

This manual covers the general subject of quantitative analysis as illustrated by a large number of procedures on familiar compounds, including ores of the common metals. The course is graded so as to take up simpler determinations first, especially those that can be verified by reference to the standard literature. Thus, the first example is the determination of the water in barium chloride crystals; and it is noticeable, by the way, that the formula for barium chloride has been incorrectly written BaCl instead of $BaCl_2$. Inasmuch as this substance is a definite composition, the student has a check-up as to the correctness of analysis. At the same time there is a possible opportunity for deception, for an apt pupil might calculate what the weights should be and thus get the result without actually making the analysis. Direct supervision of the students, however, should be carried out, which would prevent this. The exercises then proceed to more complex questions, ending up with delicate methods of analysis, as the determination of small amounts of arsenic and methods of determining traces of chlorine in water.

The book contains a good deal of material useful to the student and with the careful supervision of laboratory assistants, as above noted, a good training should be obtained from it. HENRY LEFFMANN.

CALCUL GRAPHIQUE DES POUTRES CONTINUES À SECTION CONSTANTE, NOUVELLE MÉTHODE GRAPHIQUE PERMETTANT DE DÉTERMINER LES MOMENTS FLÉCHISSANTS SUR APPUIS. Par Thomas Kluz, Ingénieur des Ponts et Chaussées, Lwow, Pologne. 53 pages, 8vo, paper. Paris, Le Constructeur de Ciment Armé, 1926. Price, 12 f. 50.

Graphical and diagrammatic methods of calculation have received the widest application in the solution of engineering problems for many years and their use has effected marked economies in the engineering-office costs of

every type of design project. The variety and abundance of these often highly ingenious devices and methods are familiar to all readers of technical literature. How much in favor graphical methods have become in the engineering office may be gleaned from a further step in the same direction of the recent application of direct measurement of small-scale models for the determination of the deformations and stresses in statically indeterminate structures.

In this essay, the author develops some apparently overlooked territory of the field of graphic calculation in presenting a geometrical construction for determining the moments at the supports of continuous beams. The method is applicable only to beams of uniform section, but the loading may be of any kind and the span-lengths may be unequal. The basis of the method is the expression of the Clapeyron formula of three moments in a form which may be represented by geometric construction. First the case of a beam of two spans with the ends unrestrained is considered. Then a construction for determining the moments at the supports for three and four spans and finally the general case of a beam of n-spans. The values for beams with end-restraint are derived as limiting cases of beams of greater number of spans than those under restraint, that is, by taking equal to zero the length of span adjacent to a restrained support.

The demonstrations with their analytical relationships are made with great clarity and in the fullest detail. The work is a clever contribution in graphical calculation which should prove of rare interest and great utility to designing engineers. LUCIEN E. PICOLET.

DIGEST OF PATENTS RELATING TO COAL-TAR DYES AND ALLIED COMPOUNDS. Prepared by Aida M. Doyle, Special Agent, Bureau of the Census. vii–585 pages, 8vo. Easton, Penna., The Chemical Publishing Company, 1926. Price, $20.

"Thanks to the coöperation of theory and practise, the coal-tar color industry of Germany has conquered the world." This was the introductory sentence in the preface of Theodore Weyl's essay on the "Sanitary Relations of the Coal-tar Colors," published many years ago and translated into English by the writer of this review. Weyl referred to a peaceful conquest; a control of the dye-making industry by the efficiency and progressiveness of the German plants. Recent occurrences have shown that another kind of conquest was almost in German hands as a result of this coöperation. When Perkins made the first synthetic color, no one foresaw the vast industry that the procedure initiated not only in the color-industry, but in other fields such as therapeutics, explosives and reagents for the laboratory.

In the early days of the German color-industry, indifference towards the subject was a noticeable attitude of British and French scientists and captains of industry. Not infrequently sarcastic allusions were made to the theories of molecular structure offered. To-day those theories are dominant. Kekulé's suggestion of the six-carbon ring in benzene was probably the most fertile of any purely inferential suggestion in science. It is an interesting speculation as to what organic chemistry would be if aliphatic groupings alone existed, for it seems positive that the immense extent of synthetic chemistry is due mainly to the rigidity that the ring form gives to the molecule.

The late war showed vividly the close relation between the color industry and the manufacture of warlike stores. The thorough and extensive organization of Germany for the former enabled an almost instantaneous diversion of its plants to the latter purposes. Peace was followed by a prompt return to original operations, but in the meanwhile, partly from necessity and partly from the wisdom that comes through painful experience, the great nations that were at war with Germany have followed in its footsteps, have encouraged research, built up partial dye and explosive industries, and, what is equally important, secured some interest in research for research's sake on the part of the influential portion of their peoples.

Concerning the volume in hand little can be said except in formal praise. It is, of course, not intended for instruction or for perusal. It is a comprehensive enumeration of the patents that have been issued in the United States prior to January 1, 1924, relating to color manufacture and to the accessory products, especially those known as "Intermediates." It will be extremely valuable, indeed, absolutely necessary to all engaged in such industries and to all libraries established for assistance to those working in applied chemistry. It will save to such many hours of tedious search. In conjunction with Lange's excellent work on "Intermediates" reviewed in this JOURNAL some years ago, the color chemist will have most valuable reference material. It is profitable for Americans to glance over the earlier pages and note that most of the patents in the initial years of the industry were granted to Germans. One interesting feature is necessarily left unnoticed (the book being a chronicle only), that is the erroneous descriptions of certain processes discovered during the war, when American chemists tried to make colors. The preparation of the work was one of great labor and chemists and manufacturers interested in the field to which it is devoted must be thankful for the data presented.

HENRY LEFFMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS. Report 235, Interaction between Air Propellers and Airplane Structures. By W. F. Durand. 23 pages, illustrations, diagrams, tables, quarto. Washington, Government Printing Office, 1926. Price, ten cents.

This investigation was conducted at the Leland Stanford Junior University by the National Advisory Committee for Aeronautics at the request of and with funds provided by the Army Air Service.

The purpose of the investigation, the results of which are presented in this report, was the determination of the character and amount of interaction between air propellers as usually mounted on airplanes and the adjacent parts of the airplane structure—or, more specifically, those parts of the airplane structure within the wash of the propeller, and capable of producing any significant effect on propeller performance.

In Report No. 177, by Messrs. Lesley and Woods, such interaction between air propellers and certain simple geometrical forms was made the subject of investigation and report. The present investigation aims to carry this general study one stage further by substituting actual airplane structures for the simple geometrical forms.

From the point of view of the present investigation, the airplane struc-

tures, viewed as an obstruction in the wake of the propeller, must also be viewed as a necessary part of the airplane and not as an appendage which might be installed or removed at will.

Report 244, Aerodynamic Characteristics of Airfoils—IV, Continuation of Reports Nos. 93, 124 and 182. By the National Advisory Committee for Aeronautics. 40 pages, illustrations, quarto. Washington, Government Printing Office, 1926. Price, twenty cents.

This collection of data on airfoils has been made from the published reports of a number of the leading aerodynamic laboratories of this country and Europe. The information which was originally expressed according to the different customs of the several laboratories is here presented in a uniform series of charts and tables suitable for the use of designing engineers and for purposes of general reference.

It is a well-known fact that the results obtained in different laboratories, because of their individual methods of testing, are not strictly comparable even if proper scale corrections for size of model and speed of test are supplied. It is, therefore, unwise to compare too closely the coefficients of two wing sections tested in different laboratories. Tests of different wing sections from the same source, however, may be relied on to give true relative values.

The series of airfoils designated N.A.C.A.-M1 to N.A.C.A.-M27 were tested in the variable density wind-tunnel of the National Advisory Committee for Aeronautics at a pressure of approximately 20 atmospheres.

The absolute system of coefficients has been used, since it is thought by the National Advisory Committee for Aeronautics that this system is the one most suited for international use and yet it is one from which a desired transformation can be easily made. For this purpose a set of transformation constants is given.

Each airfoil section is given a reference number, and the test data are presented in the form of curves from which the coefficients can be read with sufficient accuracy for designing purposes. The dimensions of the profile of each section are given at various stations along the chord in per cent. of the chord, the latter also serving as the datum line. The shape of the section is also shown with reasonable accuracy to enable one to more clearly visualize the section under consideration, together with its characteristics.

The authority for the results here presented is given as the name of the laboratory at which the experiments were conducted, with the size of model, wind velocity, and year of test.

PUBLICATIONS RECEIVED.

Surface Equilibria of Biological and Organic Colloids, by P. Lecomte du Noüy, D.Sc. Introductions by Dr. Alexis Carrel and Prof. Robert A. Millikan. American Chemical Society Monograph Series. 212 pages, illustrations, 8vo. New York, The Chemical Catalog Company, Inc., 1926. Price, $4.50.

Chemistry in the World's Work, by Harrison E. Howe. 244 pages, illustrations, 12mo. New York, D. Van Nostrand Company, 1926. Price, $3.

The Enlarged Heat Drop Tables, H. P. Gauge Pressures, L. P. Absolute Pressures. Calculated by Herbert Moss, D.Sc., from the formulæ and enlarged steam tables of Prof. H. L. Callendar, LL.D. 88 pages, 8vo. London,

Edward Arnold and Company, and New York, Longmans, Green and Company, 1925. Price, $3.75.

Enlarged Mollier or H-φ Diagram for Saturated and Superheated Steam. Plotted by Prof. H. L. Callendar, F.R.S. Prepared for the Turbine Section of the British Electrical and Allied Manufacturers' Association. 29 × 38 inches. New York, Longmans, Green and Company. Price, $1.35.

The Modern Soap and Detergent Industry, Including Glycerol Manufacture. A complete practical treatise in three volumes on the manufacture of laundry, toilet, pharmaceutical, textile, abrasive, scouring and powdered soaps; also detergent compositions and soap substitutes of all kinds. By Geoffrey Martin, D.Sc., Ph.D. Volume 3—The Manufacture of Glycerol. Variously paged, illustrations, plates, 8vo. London, Crosby Lockwood and Son, 1926. Price, 30 shillings, net.

Calcul Graphique des Poutres Continues à Section Constante. Nouvelle méthode graphique permettant de déterminer les moments fléchissants sur appuis, par Thomas Kluz. 53 pages, illustrations, 8vo. Paris, Le Constructeur de Ciment Armé, 1926.

Abridged Scientific Publications from the Research Laboratories of the Eastman Kodak Company. Vol. ix, 1925. 224 + vi pages, illustrations, diagrams, tables, 8vo. Rochester, Eastman Kodak Company, 1925.

National Advisory Committee for Aeronautics: Technical Notes, No. 242, Improving the Performance of a Compression Ignition Engine by Directing Flow of the Inlet Air, by Carlton Kemper. 9 pages, plates, quarto. No. 243, The Characteristics of the N.A.C.A. M-12 Airfoil Section by George J. Higgins. 6 pages, plates, tables, quarto. No. 244, Navy Propeller Section Characteristics as Used in Propeller Design, by Fred E. Weick. 7 pages, plates, quarto. No. 245, Report on Tests of Metal Model Propellers in Combination with a Model VE-7 Airplane, by E. P. Lesley. 21 pages, plates, tables, quarto. Washington, Committee, 1926.

Digest of Patents Relating to Coal-tar Dyes and Allied Compounds, prepared by Aida M. Doyle. 585 pages, 8vo. Easton, Penna., The Chemical Publishing Company, 1926. Price, $20.

Feuerfeste Baustoffe für Kammern der Kokerei- und Gaswerksöfen, von L. Litinsky. 50 pages, illustrations, 8vo. Halle (Saale) W. Knapp. Price, 2.80 R. M.

Über die Wahl eines Gaswerksofensystems, von L. Litinsky. 29 pages, illustrations, diagrams, 8vo. Halle (Saale) W. Knapp. Price, 1.50 R. M.

Inorganic Quantitative Chemical Analysis, by Wilfred W. Scott. 178 pages, illustrations, tables, 8vo. Easton, Penna., The Chemical Publishing Company, 1926. Price, $2.50.

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112 pages, plates, tables, diagrams, 8vo. Price, fifty cents. No. 317, Action of Sodium Sulphate in Synthetic Tannin Materials, by E. Wolesensky. 20 pages, 8vo. Price, ten cents. Circular No. 304, Properties and Manufacture of Concrete Building Units. 49 pages, illustrations, 8vo. Price, twenty cents. Washington, Government Printing Office, 1926.

Charles Dayton Woods.—A biographical sketch of the late Charles Dayton Woods has been written by JAMES M. BARTLETT (*Jour. Asso. Official Agri. Chemists,* 1926, **9**, pages iii–v). Woods was born in Brooks, Me., September 11, 1856, and died at Newton, Mass., March 30, 1925. He was educated under W. O. Atwater at Wesleyan University, and was associated with Atwater from 1880 to 1896 at the University and the Storrs Agricultural Experiment Station. They demonstrated the utilization of the free nitrogen of the atmosphere by certain growing plants, such as peas. They developed an efficient bomb calorimeter and an excellent respiration calorimeter, and were the first to publish caloric values of foods and feeding stuffs in the United States. In addition to the work in agricultural chemistry, Atwater and Woods made elaborate studies on the food and nutrition of man. The tables of Atwater and Woods on the chemical composition and the caloric value of American food materials are in daily use by physiologists, dietitians and physicians. For almost a quarter-century, beginning in 1896, Woods served as director of the Maine Agricultural Experiment Station and, during the first eight years of this period, was also professor of agriculture in the University of Maine. Woods conducted researches in nutrition and agricultural chemistry, and was active in obtaining the passage of laws by the legislature providing for the inspection of feeding stuffs, agricultural seeds, and foods and drugs. During the last years of his life, Woods served as consultant in agriculture to the U. S. War Department, and as technical adviser in agricultural science for the State of Massachusetts. J. S. H.

Use of Cocoa By-products as Fertilizer Materials. (U. S. Department of Agriculture.)—Until within the last few years the only cocoa by-product in this country cheap enough to be of interest to the fertilizer industry was the shells, with such related waste material as cocoa dust and sweepings. As a result of the enormous demand for cacao butter, however, two additional by-products of importance are now being produced in large quantities, and they have been obtainable at prices which have made them available for use as fertilizer materials. These are the cocoa press cake and solvent-extracted cocoa. The latter is the defatted residue left after extracting the cacao fat from the press cake with benzol. Formerly cacao butter was produced incidentally to the manufacture of cocoa powder. Now it is one of the primary products of the cacao bean.

Utilization of cocoa by-products as fertilizer materials is in more or less active competition with their use as feedstuffs and as sources

of theobromine alkaloid and caffeine. Until recently about one-fourth of the by-product cake produced was eventually consumed as fertilizer.

Ground cocoa cake has been reported by manufacturers to be satisfactory as a "rough ammoniate" filler and conditioner in mixed fertilizers. For use as fertilizer material average press cake might be expected to bring 80 per cent. as much per ton as the solvent-extracted cocoa.

An ideal system for the utilization of by-product cocoa cake would provide for: (1) Recovery of the fat; (2) recovery of the alkaloids; and (3) retention of the valuable food and fertilizer constituents in the defatted, dealkaloidized residue.

Radio in Foreign Lands.—The steadily increasing popularity of radio throughout the world is strikingly revealed in a trade bulletin made public by the Commerce Department. While the United States is still supreme in the radio field—having three-fifths of the world's broadcasting stations and five times more receiving sets in use than any other country—foreign nations are awakening to the immense possibilities of radio as a medium of education and entertainment. Last year radio equipment exported from the United States was valued at $10,000,000, which was 80 per cent. more than the value of shipments in 1924 and ten times the figure for 1921.

Broadcasting stations, according to the report, are now operating in every corner of Europe; there are stations in the larger cities of South America, Australia, and South Africa. Japan and India in Asia also have broadcasting stations, although radio development naturally has not been so great in these countries as in other parts of the world. These broadcasting stations range in power from 16,000 watts at Daventry, England—a super-station built for foreign broadcasting—to numerous smaller stations of 1000 watts and less scattered throughout the world.

The United States, the report points out, is the only important country where the radio fan can listen in free of charge. License fees exist in almost every country, ranging from the nominal one franc per year in France to $18 in Salvador and $13 in Lithuania. In the British Isles the fee is 10 shillings; in Sweden about $2.70; Japan's fee is 80 cents; and the Union of South Africa $1.25.

Along with license fees in many countries there exist rules and regulations of various kinds in connection with radio broadcasting and reception. In Greece, for example, only a Greek can own a radio set and even he is subject to government restrictions; Germany does not allow persons of Slav origin to own radio sets; the Latin-American countries have also numerous regulations which must be observed by radio operators.

Next to the United States, the report shows, the United Kingdom has gone the furthest in radio development with 35.6 sets per thousand population. Sweden ranks next with 30.3 sets per thousand

population, followed by the Union of South Africa, Denmark, Austria, Germany and France. The development of radio in Sweden has been outstanding, the report reveals. Up to about the beginning of 1924 there was practically no market at all for radio equipment, largely because of the total lack of broadcasting and government restrictions. On March 31st last not far from 200,000 sets were licensed throughout the country.

The type of matter broadcast from the various foreign stations varies widely. Much attention is given to music and there is a general absence of "jazz." The programs differ from those of this country in that much more attention is given to current news and there is a tendency in some sections to use the radio for advertising. In Brazil a radio society is preparing to broadcast daily for the benefit of the wealthy planters in the state of Sao Paulo all the latest coffee news together with quotations.

In Northern and Central Europe the climate is ideal for continuous radio reception. The Germans in Berlin can tune in without trouble and listen to a musical program broadcast from Rome; getting Paris is no feat at all, and the stations in Northern Europe may be easily heard. The Frenchman and the Englishman likewise find the whole of Europe at their beck and call. The rapid development of radio indicates that it is following the course of the automobile, the phonograph, and other modern inventions which have added to the pleasure and comfort of mankind.

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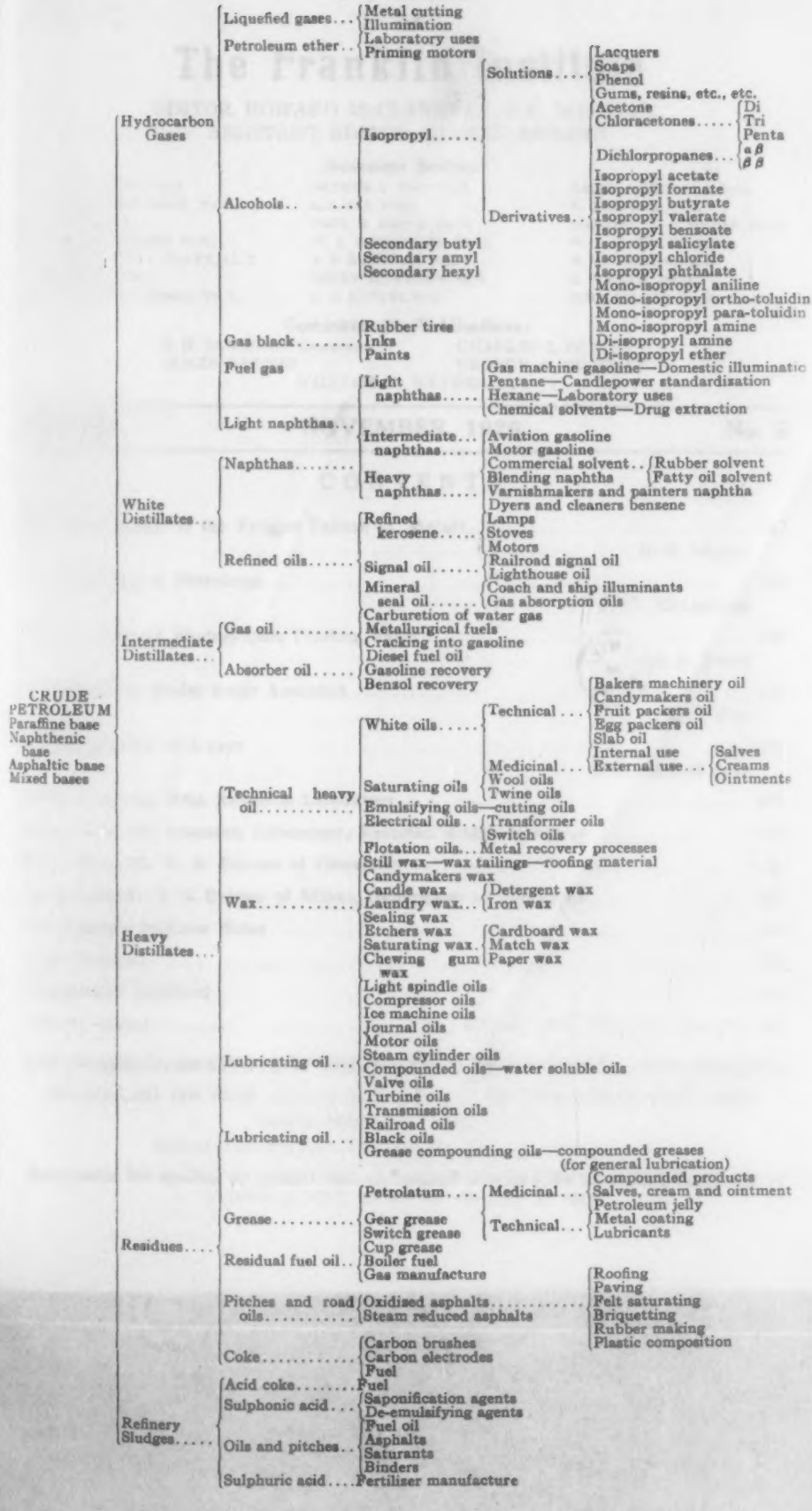

Use this chart for binding purposes in place of the copy appearing in the September number facing page 308.